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LEVEL II



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**OPTIM III: A NASTRAN COMPATIBLE LARGE SCALE
AUTOMATED MINIMUM WEIGHT DESIGN PROBLEM
— USERS AND PROGRAMMERS MANUAL**

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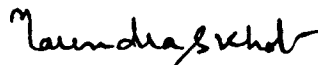
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This technical report has been reviewed and is approved for publication.



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Membrane finite elements were extended to include the capability of handling layered, orthotropic material, composite membrane plate constructions. Various failure criteria for composite materials were included as required for strength constraints in the optimization process involving the composite plates.

New NASTRAN compatible input data instructions are provided and their use demonstrated by a sample problem.

An extended programmer's manual, designed to facilitate implementation, modification, and illustration of the OPTIM III program is included.

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FOREWORD

This report describes the work performed by Bell Aerospace Textron, a Division of Textron, Inc., Buffalo, New York. The work was sponsored by the Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under Contract F33615-77-C-3032.

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The contracted work was performed between June 1977 and October 1979.

The work was performed in the Advanced Mobility System Department, Bell Aerospace Textron. Mr. Richard D. Thom was the Technical Director of the study.

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I. INTRODUCTION

The weight optimization computer program OPTIM II, Reference 1, was altered to make its input format compatible with the widely used NASTRAN program. The resulting new program is called OPTIM III. Accomplishment of this objective required the modification and addition of many subroutines.

Included in the new program, OPTIM III, is the capability of analyzing and optimizing structures which contain composite membrane plates. The method of approach adopted for analysis of composite membrane plates involves the stacking of triangle and quadrilateral orthotropic membrane plate elements and is discussed in Section II. Also included in Section II is a summary of the three types of failure criteria for composite materials in a state of plane stress which are available in OPTIM III for use in connection with the optimization process.

The theoretical bases for the triangle and quadrilateral orthotropic membrane plates inserted into OPTIM III is given in Section III which also includes a summary of all the eight finite elements available.

All NASTRAN compatible input data cards are described in Section IV and their utilization is illustrated by a sample problem in Section V.

A programmer's manual which describes the computer program OPTIM III in detail is presented in the appendix. The information presented in the appendix is geared specifically to the programmer and includes the general program logic, external file structure and detailed descriptions of the subroutines.

II. OPTIMIZATION OF STRUCTURES CONTAINING COMPOSITE PLATES

A. General

The membrane triangle and quadrilateral plate element originally included in OPTIMII were extended to handle composite plate constructions. The type of composite structures accepted by the optimization program is limited to flat composite plates composed of orthotropic layers of material. Each layer of the plate composite is idealized as a separate finite membrane plate element which is discussed later in this section.

When modeling a composite plate consisting of many layers, the gridpoints of all the membrane elements or layers of the plate are selected to be the same. This restriction ensures that each of the layers of the composite plate is subjected to the same deformation state and is in conformance with small displacement plate theory in which it is assumed that straight normals to the plate median surface before deformation remain straight after deformation. To ensure that this condition is satisfied, the layers of the plate composite must be oriented symmetrically with respect to the median surface of the composite plate.

Various failure criteria for composite materials were investigated and of these three types of criteria were included in OPTIMIII. These three types of criteria which are required in the optimization process for the layers in the composite plate are discussed in this section. (Reference 6, 7, 8).

B. Analysis with Orthotropic Membrane Elements

Each layer in a composite membrane plate is assumed to be composed of fibers imbedded in a matrix material. The fibers are assumed to be oriented in such a way as to result in their characterization as an orthotropic material. A typical orthotropic layer of this type is illustrated in Figure 1. Coordinates X_m , Y_m shown in the figure are the material axis of orthotropy in which the X_m axis is oriented parallel to the fibers.

Two types of orthotropic membrane plate finite elements are available in the optimization program and they are,

1. Triangle membrane element
2. Quadrilateral membrane element

These two finite elements are displayed in Figure 2. The angle θ gives the orientation of the material axis with respect to the side connecting gridpoints 1 to 2. Note that for the triangle the material axis orientation angle θ is measured from side 1-2 to the material axis X_m whereas for the quadrilateral it is measured from the material axis X_m to the side 1-2.

The relationship between the elastic stresses and strains for an orthotropic material in plane stress referenced to the material axis of orthotropy shown in Figure 1 is given by

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix}_m = \begin{bmatrix} G_{11} & G_{12} & G_{13} \\ G_{21} & G_{22} & G_{23} \\ G_{31} & G_{32} & G_{33} \end{bmatrix} \begin{Bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_{xy} \end{Bmatrix}_m$$

where

$$\Delta = 1 - \mu_{xy} \mu_{yx}, \quad \frac{\mu_{xy}}{\mu_{yx}} = \frac{E_x}{E_y}$$

$$G_{11} = \frac{E_x}{\Delta}, \quad G_{12} = \frac{E_y \mu_{xy}}{\Delta}, \quad G_{13} = 0.0$$

$$G_{21} = G_{12}, \quad G_{22} = \frac{E_y}{\Delta}, \quad G_{23} = 0.0$$

$$G_{31} = G_{13}, \quad G_{32} = G_{23}, \quad G_{33} = G_{xy}$$

These stress-strain relations were used in the development of the membrane plate elements and reduced down to isotropic material properties. This situation makes it possible to construct a composite membrane plate composed of fiber-reinforced orthotropic materials and isotropic metallic-type materials.

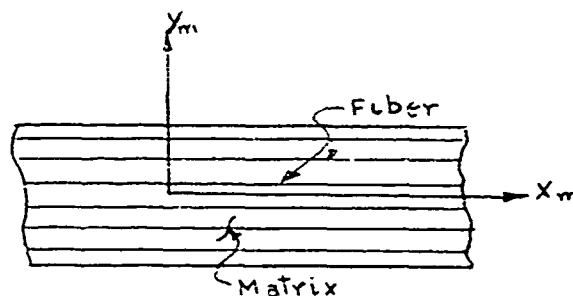
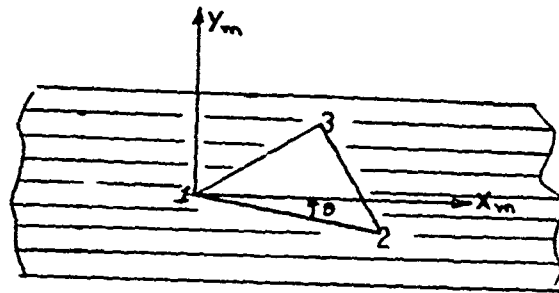
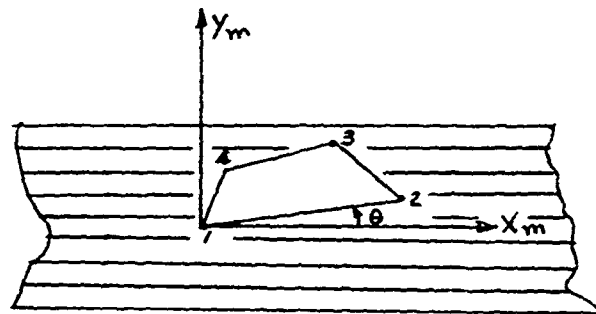


Figure 1. Typical fiber-reinforced layer in a composite membrane plate

The stresses are computed for both element types with respect to the material axis of orthotropy and are used in the failure criteria formulation discussed in the next section.



a. Triangle



b. Quadrilateral

Figure 2. Orientation of membrane elements in fiber-reinforced composite layer

C. Criteria of Failure

Three types of criteria of failure have been inserted into the optimization program. They are

- a. Modified Von Mises or energy of distortion criterion of failure
- b. Maximum Stress Theory
- c. Maximum Strain Theory

In all of these theories, the applied stresses σ_x , σ_y and σ_{xy} are referred to the material axes of orthotropy.

The modified distortion energy criterion of failure is given by

$$\left(\frac{\sigma_x}{F_x}\right)^2 + \left(\frac{\sigma_y}{F_y}\right)^2 - \frac{\sigma_x \sigma_y}{F_x F_y} + \left(\frac{\sigma_{xy}}{F_{xy}}\right)^2 = 1$$

where F_x and F_y are tensile (compression) failure stresses and F_{xy} is the shear failure stress. These failure stresses are determined for simple load test conditions with respect to the axis of orthotropy.

The maximum stress theory postulates that failure will occur when any one of the three applied stresses is equal to its corresponding failure stress. Thus failure occurs when any one of the following conditions is satisfied

$$\sigma_x = F_x$$

$$\sigma_y = F_y$$

$$\sigma_{xy} = F_{xy}$$

In the above two theories tension or compression failure stresses are selected in consistency with the sign of the applied stresses. Failure stresses F_x , F_y and F_{xy} represent longitudinal, transverse, and shear modes of failure.

For the maximum strain theory it is assumed that failure is precipitated when any one of the applied strain components referred to the material axis attains its limiting failure strain. Thus for an orthotropic material the conditions of failure are

$$\begin{aligned}\epsilon_x &= \bar{\epsilon}_x \\ \epsilon_y &= \bar{\epsilon}_y \\ \gamma_{xy} &= \bar{\gamma}_{xy}\end{aligned}$$

where $\bar{\epsilon}_x$, $\bar{\epsilon}_y$ and $\bar{\gamma}_{xy}$ are the failure strains. Note that a negative applied strain implies a compression failure strain. The condition of failure in terms of stresses are

$$\begin{aligned}\bar{\epsilon}_x E_{xx} &= \sigma_{xx} + M_{xy} \sigma_{yy} \\ \bar{\epsilon}_y E_{yy} &= \sigma_{yy} + M_{xy} \frac{E_{xx}}{E_{yy}} \sigma_{xx} \\ \bar{\gamma}_{xy} G_{12} &= \tau_{xy}\end{aligned}$$

Implementation of the above three failure criteria requires a knowledge of the following ten material failure properties: $\pm F_x$, $\pm F_y$, F_{xy} , $\pm \bar{\epsilon}_x$, $\pm \bar{\epsilon}_y$, $\bar{\gamma}_{xy}$.

NOTE: $M = \mu$ Poissons Ratio

III. NEW ORTHOTROPIC PLATE ELEMENTS

A. General

As noted in Reference 1, the usefulness of an optimization program stems from the accuracy with which the real structure can be represented by the finite element model. In the OPTIM II program there are eight elements available for the analysis of a structure fabricated from isotropic materials. A major task of the present work was not only to put OPTIM II into a form compatible with NASTRAN but to extend its capability to include composite plate structures. In this latest version of OPTIM II there are eight elements as shown in Figure 3 with their program names and they are:

1. Axial Force Member
2. Pure Shear and Shear Web Elements
3. Triangular Plate in Plane Stress
4. Quadrilateral Plate in Plane Stress
5. Tubular Beam Element
6. Midpoint Axial Force Member
7. Midpoint Triangular Plate in Plane Stress
8. Midpoint Quadrilateral Plate in Plane Stress

The first three elements in the above list were in the pilot optimization program, OPTIM (Reference 2) and the remaining five added when OPTIM II was written. Explicit formulations for the element stiffness and other matrices are given in Reference 2 for the first five elements

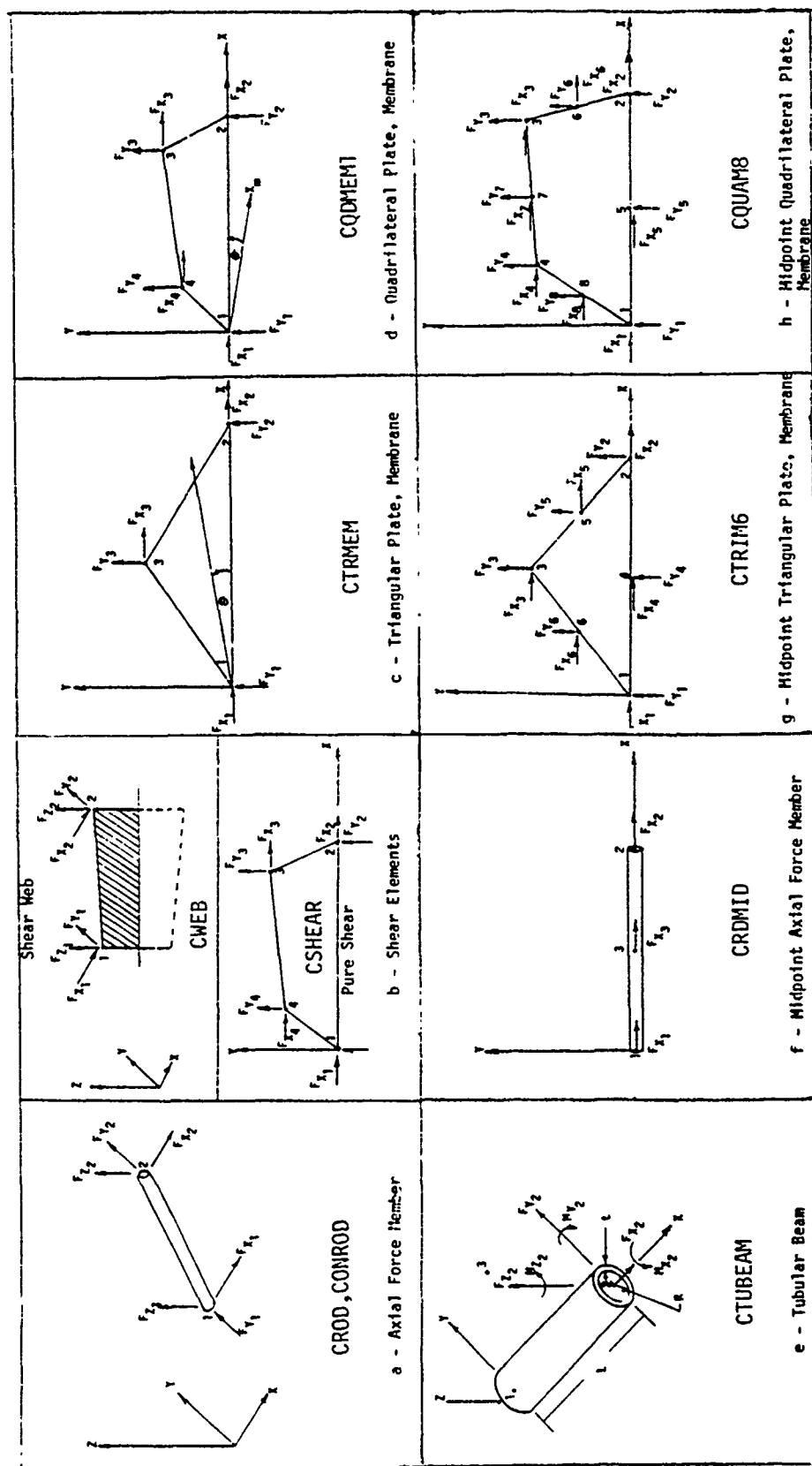


FIGURE 3. FINITE ELEMENT LIBRARY

in the above list. Formulations for the last three elements are given in Reference 1. The triangular and quadrilateral membrane plate elements, number 3 and 4, were extended to include orthotropic plate properties and the details of this extension are given in the next two sections.

B. Triangular Membrane Plate

The triangular plate in plane stress originally contained in the OPTIM II program was extended to include orthotropic material properties. The location of the material axis of orthotropy (X_m, Y_m) is shown in Figure 3C, and is referred to the local reference axes (X, Y) of the triangle by the angle θ . A description of the procedure used to compute the stiffness and stress matrices is given below. Theoretical background for the procedure is given in References 2, 3 and 5.

As shown in Reference 2, the stiffness matrix referred to the local axis system is given by

$$[K] = t[B^{-1}]^T [A^*] [B^{-1}] \quad (3.1)$$

where

$$[B]^{-1} = \frac{1}{x_2 y_3 - x_3 y_2} \begin{bmatrix} (x_2 y_3 - x_3 y_2) & 0 & 0 & 0 & 0 & 0 \\ -y_{3-2} & y_3 & -y_2 & 0 & 0 & 0 \\ x_{3-2} & -x_3 & x_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & (x_2 y_3 - x_3 y_2) & 0 & 0 \\ 0 & 0 & 0 & -y_{3-2} & y_3 & -y_2 \\ 0 & 0 & 0 & x_{3-2} & -x_3 & x_2 \end{bmatrix} \quad (3.2)$$

The matrix $[A^*]$ is given by

$$[A^*] = [T] [G_e] [T]^T \quad (3.4)$$

where the transformation matrix $[T]$ is :

$$[T] = \begin{bmatrix} 0. & 0. & 0. \\ 1.0 & 0. & 0. \\ 0. & 0. & 1.0 \\ 0. & 0. & 0. \\ 0. & 0. & 0. \\ 0. & 1.0 & 0. \end{bmatrix} \quad (3.5)$$

For isotropic materials the material matrix $[G_e]$ in Equation (3.4) is given by

$$[G_e] = \begin{bmatrix} \frac{E}{1-M^2} & \frac{ME}{1-M^2} & 0 \\ \frac{ME}{1-M^2} & \frac{E}{1-M^2} & 0 \\ 0. & 0. & G \end{bmatrix} \quad (3.6)$$

and for orthotropic material:

$$[G_e] = [U]^T [G_m] [U] \quad (3.7)$$

where the rotation transformation matrix $[U]$ of strain components is given by

$$[U] = \begin{bmatrix} \cos^2\theta & \sin^2\theta & \cos\theta\sin\theta \\ \sin^2\theta & \cos^2\theta & -\cos\theta\sin\theta \\ -2\cos\theta\sin\theta & 2\cos\theta\sin\theta & \cos^2\theta - \sin^2\theta \end{bmatrix} \quad (3.8)$$

The elements of the material matrix $[G_m]$ are defined in terms of orthotropic material properties as follows:

$$\begin{aligned}
 G_{11} &= \frac{E_x}{\Delta} & G_{12} &= \frac{E_y M_{xy}}{\Delta} & G_{13} &= 0.0 \\
 G_{21} &= G_{12} & G_{22} &= \frac{E_y}{\Delta} & G_{23} &= 0.0 \\
 G_{31} &= G_{13} & G_{32} &= G_{23} & G_{33} &= G_{xy}
 \end{aligned} \tag{3.9}$$

$$\Delta = 1 - M_{xy} M_{yx}, \quad \frac{M_{xy}}{M_{yx}} = \frac{E_x}{E_y}$$

The membrane stresses, assumed constant in the element, are given with reference to the material axis of orthotropy by

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix} = [S] \{u_e\} \tag{3.10}$$

where

$$[S] = [D] [B^{-1}] \tag{3.11}$$

$$[D] = [T_1] [T] [G_e] [T]^T [B^{-1}] \tag{3.12}$$

$$[T_1] = \begin{bmatrix} 0. & 1. & 0. & 0. & 0. & 0. \\ 0. & 0. & 1. & 0. & 0. & 0. \\ 0. & 0. & 0. & 0. & 0. & 1. \end{bmatrix} \tag{3.13}$$

C. Quadrilateral Membrane Plate

The quadrilateral membrane plate, Figure 3d, is a linear stress variation element originally developed by Turner⁽⁴⁾ for isotropic materials ($\theta = 0$) and used subsequently in many analysis and optimization programs. For this element, the design variable is the plate thickness and the stress variations are given by

$$\sigma_x = a_1 + a_2 y$$

$$\sigma = a_3 + a_4 x$$

$$\gamma_{xy} = a_5$$

This element was extended to include orthotropic material properties, and theoretical details of the extension are given in Reference 3. However, the element matrices developed in Reference 3 were referred to the material axis and to make them compatible with the OPTIM II program, material to local axis transformation had to be introduced.

The stiffness matrix for the quadrilateral membrane plate referred to the local element axis is given by

$$[K] = t[T_2]^T [B^{-1}]^T [A^*] [B^{-1}] [T_2] \quad (3.14)$$

where:

$$[B] = \frac{1}{E_X} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ & x_2 y_2 & -\mu_{XY} x_2 & -\frac{\mu_{XY} x_2^2 - E_X y_2^2}{2} & 0 & y_2 & 1 & 0 \\ x_3 & x_3 y_3 & -\mu_{XY} x_3 & -\frac{\mu_{XY} x_3^2 - E_X y_3^2}{2} & 0 & y_3 & 1 & 0 \\ x_4 & x_4 y_4 & -\mu_{XY} x_4 & -\frac{\mu_{XY} x_4^2 - E_X y_4^2}{2} & 0 & y_4 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{E_X}{E_Y} \\ -\mu_{XY} y_2 & -\frac{\mu_{XY} y_2^2 - x_2^2}{2} & \frac{E_X}{E_Y} y_2 & \frac{E_X}{E_Y} x_2 y_2 & \frac{E_X x_2}{G_{XY}} & -x_2 & 0 & \frac{E_X}{E_Y} \\ -\mu_{XY} y_3 & -\frac{\mu_{XY} y_3^2 - x_3^2}{2} & \frac{E_X}{E_Y} y_3 & \frac{E_X}{E_Y} x_3 y_3 & \frac{E_X x_3}{G_{XY}} & -y_3 & 0 & \frac{E_X}{E_Y} \\ -\mu_{XY} y_4 & -\frac{\mu_{XY} y_4^2 - x_4^2}{2} & \frac{E_X}{E_Y} y_4 & \frac{E_X}{E_Y} x_4 y_4 & \frac{E_X x_4}{G_{XY}} & -x_4 & 0 & \frac{E_X}{E_Y} \end{bmatrix} \quad (3.15)$$

$$[A^*] = \frac{t}{E_X} \begin{bmatrix} A & I_Y & -\mu_{XY} A & \mu_{XY} I_X & 0 & 0 & 0 & 0 \\ I_Y & I_Y^2 & -\mu_{XY} I_Y & -\mu_{XY} I_{XY} & 0 & 0 & 0 & 0 \\ -\mu_{XY} A & -\mu_{XY} I_Y & \frac{E_X}{E_Y} A & \frac{E_X}{E_Y} I_X & 0 & 0 & 0 & 0 \\ -\mu_{XY} I_X & -\mu_{XY} I_{XY} & \frac{E_X}{E_Y} I_X & \frac{E_X}{E_Y} I_X^2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{E_X A}{G_{XY}} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (3.16)$$

The matrix $[T_2]$ transforms the element displacements from the material axis of orthotropy to the local element axis and is given by

$$[T_2] = \begin{matrix} & \begin{matrix} u_{1m} & u_{2m} & u_{3m} & u_{4m} & v_{1m} & v_{2m} & v_{3m} & v_{4m} \end{matrix} \\ \begin{matrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ v_1 \\ v_2 \\ v_3 \\ v_4 \end{matrix} & \begin{bmatrix} \cos\theta & 0 & 0 & 0 & -\sin\theta & 0 & 0 & 0 \\ 0 & \cos\theta & 0 & 0 & 0 & -\sin\theta & 0 & 0 \\ 0 & 0 & \cos\theta & 0 & 0 & 0 & 0 & 0 \\ \sin\theta & 0 & 0 & \cos\theta & 0 & 0 & -\sin\theta & 0 \\ 0 & \sin\theta & 0 & 0 & \cos\theta & 0 & 0 & -\sin\theta \\ 0 & 0 & \sin\theta & 0 & 0 & \cos\theta & 0 & 0 \\ 0 & 0 & 0 & \sin\theta & 0 & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 0 & \sin\theta & 0 & 0 & \cos\theta \end{bmatrix} \end{matrix} \quad (3.17)$$

Membrane stresses in the quadrilateral membrane plate element are given by Equation 3.10 with the stress matrix defined as

$$[S] = [D][B^{-1}][T_2] \quad (3.18)$$

where matrix $[B]$ is given by Equation 3.15, transformation matrix $[T_2]$ by Equation 3-17 and the $[D]$ matrix by the following:

$$[D] = \begin{bmatrix} 1 & 0 & 0 & 0 & Y_m & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & X_m & 0 & 0 & 0 & 0 \end{bmatrix} \quad (3.19)$$

where X_m , Y_m are referred to the material axis.

Stresses used in the failure criteria for the quadrilateral membrane plate are located at its centroid which has the coordinates

$$\begin{aligned}\bar{X}_m &= \frac{X_{1m} + X_{2m} + X_{3m} + X_{4m}}{4} \\ \bar{Y}_m &= \frac{Y_{1m} + Y_{2m} + Y_{3m} + Y_{4m}}{4}\end{aligned}\tag{3.20}$$

IV. PROGRAM INPUT DESCRIPTION

A. Input Overview

This section describes the input data required to execute the NASTRAN compatible optimization program OPTIM III.

OPTIM III was developed such that most of the input data cards are in NASTRAN format. This input consists of a deck beginning with "BEGIN BULK" and ending with "ENDDATA". All data cards are optional except those defining controls, loads, grid, and boundary conditions. Elements must also be defined.

The NASTRAN input feature of submitting data in any order, either left or right adjusted, is preserved. The GRID cards, SPC cards, FORCE, MOMENT, and MAT1, MAT2 cards are similar to NASTRAN input. Figure 3 shows the OPTIM III element library and the appropriate C*TIM input code for each element. The following is a summary of OPTIM III Input Cards:

B. Definitions of Input Cards

BEGIN Bulk	First Card of Input
*Buck	Define elements which require buckling
*Buck1	Define set of elements which require buckling
CONROD	AXIAL FORCE MEMBER Property and Connection
CQUAM8	8 Noded Midpoint Quadrilateral Connection
CQDMEM1	Quadrilateral Membrane Connection Card
CRDMID	Midpoint AXIAL Force Member Connection
CROD	Axial Force Element Connection
CSHEAR	Shear Panel Element Connection
CTRIM6	Triangular 6 node midpoint membrane element connection
CTRMEM	Triangular membrane element connection
CTUBEAM	Tubular beam element connection
CWEB	Shear Web element connection
FORCE	Static load at grid point
*GCON	Generalized Constraint Components
*GPCEQN	Grid Point Constraint Equations
GRID	Grid Point Coordinates
*ICON	Individual Constraints
*LINKS	Linked group element members
MAT1	Isotropic material properties
MAT2	Anisotropic material properties
MOMENT	Static moment at a gridpoint
*OPDVIR	Selected element design variables
OPLOADS	Loads for optimization
OPTIM	Optim control parameters
PQUAM8	Property card for 8 node midpoint quadrilateral
PQDMEM1	Property card for quadrilateral membrane
PRDMID	Property card for midpoint axial force membrane

*These cards are optional and need to be input only if necessary

PROP	Property card for axial force member
PSHEAR	Property card for shear panel
PTRIM6	Property card for triangular 6 node midpoint
PTMEM	Property card for triangular membrane
PTUBEAM	Property card for tubular beam
PWEB	Property card for shear web
SPC	Single point constraint
SPC1	Sets of single point constraints
SPC1 THRU	Sets of single point constraints
TITLE	Title card information
ENDDATA	End of Data Deck

C. Input Format

In this section detail OPTIM III input card descriptions are presented in a manner similar to the NASTRAN User's Manual. That is, each data card is described individually in alphabetical order.

Input Data Card BEGIN Bulk

Description: First Card of Input

1	2	3	4	5	6	7	8	9	10
BEGIN Bulk									

This card is identical to the format of the first card used in a NASTRAN bulk data deck.

Input Data Card BUCK Buckling Elements

Description: Defines elements which require buckling calculations

Format and Example:

1	2	3	4	5	6	7	8	9	10
BUCK	SID	EL ₁	EL ₂	EL ₃	EL ₄	EL ₅	EL ₆	EL ₇	
BUCK	1	2	3	7	8	9	10	12	

Field

SID Identification number of the buckling set

EL₁, etc. Element number

Input Data Card BUCK1 Buckling Elements

Description: Defines sets of element which require buckling calculations

Format and Example:

1	2	3	4	5
BUCK1	SID	EL ₁	"THRU"	EL _n
BUCK1	1	1	THRU	17

Field

SID	Identification of the buckling set
EL ₁	Element number
EL _n	Element number

BULK DATA DECK

Input Data Card CØNRØD AXIAL FORCE MEMBER Property and Connection

Description: Defines a rod element of the structural model without reference to a property card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CØNRØD	EID	G1	G2	MID	A				
CØNRØD	2	16	17	23	2.69				

<u>Field</u>	<u>Contents</u>
EID	Unique element identification number (Integer > 0)
G1, G2	Grid point identification numbers of connection points (Integer > 0; G1 ≠ G2)
MID	Material identification number (Integer > 0)
A	Area of rod (Real)

- Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
 2. For structural problems, CØNRØD cards may only reference MAT1 material cards.

Input Data Card CQUAM8 Midpoint Quadrilateral Element Connection

Description: Defines a midpoint quadrilateral membrane element (QUAM8) of the structure.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CQUAM8	EID	PID	G1	G2	G3	G4	G5	G6	+abc
CQUAM8	10	3	1	10	11	8	9	20	SST

1	2	3	4	5	6
+abc	G7	G8			
+ST	13	16			

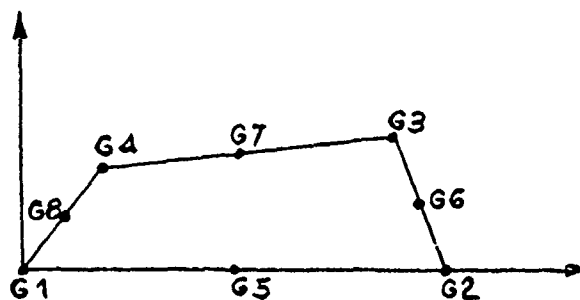
Field

Contents

EID Element identification number (Integer >0)

PID Identification number of a PQUAM8 property card

G1 through G8 Gridpoint identification numbers of connection points (Integer >0)



Remarks:

1. Element identification numbers must be unique with respect to all other element identification numbers.
2. Gridpoints G1 through G8 must be ordered as shown in the sketch of the element.
3. All interior angles must be less than 180 degrees.

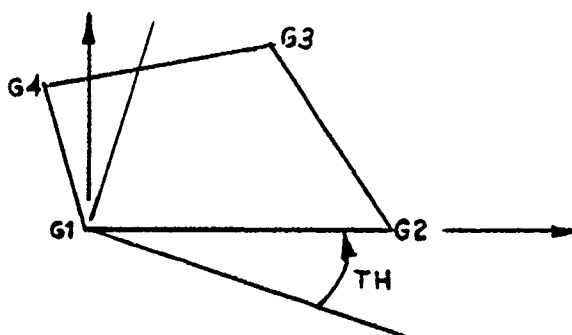
Input Data Card CQDMEM1 Quadrilateral Element Connection

Description: Defines a quadrilateral membrane element (QDMEM1) of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CQDMEM1	EID	PID	G1	G2	G3	G4	TH		
CQDMEM1	72	13	13	14	15	16	29.2		

<u>Field</u>	<u>Contents</u>
EID	Element identification number (Integer > 0)
PID	Identification number of a PQDMEM1 property card (Integer > 0)
G1,G2, G3,G4	Grid point identification numbers of connection points (Integer > 0); $G1 \neq G2 \neq G3 \neq G4$
TH	Material property orientation angle in degrees (Real). The sketch below gives the sign convention for TH.



- Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
 2. Gridpoints G1 through G4 must be ordered consecutively around the perimeter of the element.
 3. All interior angles must be less than 180 degrees.

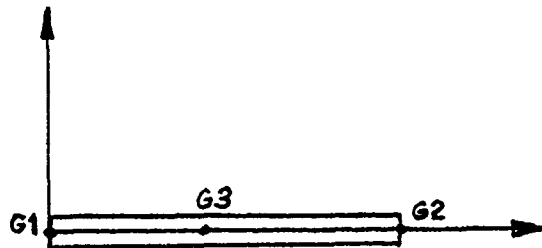
Input Data Card CRDMID Midpoint Axial Force Element Connection

Description: Defines a midpoint axial force element RDMID of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CRDMID	EID	PID	G1	G2	G3				
CRDMID	72	13	13	14	15				

<u>Field</u>	<u>Contents</u>
EID	Element identification number (Integer > 0)
PID	Identification number of a PRDMID property card (Integer > 0)
G1,G2,G3	Gridpoint identification numbers of connection points (Integer > 0); $G1 \neq G2 \neq G3$



Remarks:

1. Element identification numbers must be unique with respect to all other element identification numbers.
2. Gridpoints G1 through G3 must be ordered as shown.

Input Data Card CRØD Axial Force Element Connection

Description: Defines a tension-compression element (RØD) of the structural model

Format and Example:

1	2	3	4	5	6	7	8	9	10
CRØD	EID	PID	G1	G2	EID	PID	G1	G2	
CRØD	12	13	21	23	3	12	24	5	

<u>Field</u>	<u>Contents</u>
EID	Element identification number (Integer > 0)
PID	Identification number of a PRØD property card
G1, G2	Grid point identification numbers of connection points (Integer > 0; G1 ≠ G2)

- Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
 2. See CØNRØD for alternative method of rod definition.
 3. One or two RØD elements may be defined on a single card.

Input Data Card CSHEAR Shear Panel Element Connection

Description: Defines a shear panel element (SHEAR) of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CSHEAR	EID	PID	G1	G2	G3	G4			
CSHEAR	3	6	1	5	3	7			

<u>Field</u>	<u>Contents</u>
EID	Element identification number (Integer > 0)
PID	Identification number of a PSHEAR property card
G1, G2, G3, G4	Grid point identification numbers of connection points (Integer > 0; G1 ≠ G2 ≠ G3 ≠ G4)

- Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
 2. Grid points G1 thru G4 must be ordered consecutively around the perimeter of the element.

Input Data Card CTRIM6 Midpoint Triangular Membrane Plate
Element Connection

Description: Defines a triangular membrane element (TRIM6) of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CTRIM6	EID	PID	G1	G2	G3	G4	G5	G6	+abc
CTRIM6	220	666	100	110	120	210	220	320	BSS
+abc									
+BS	90.0								

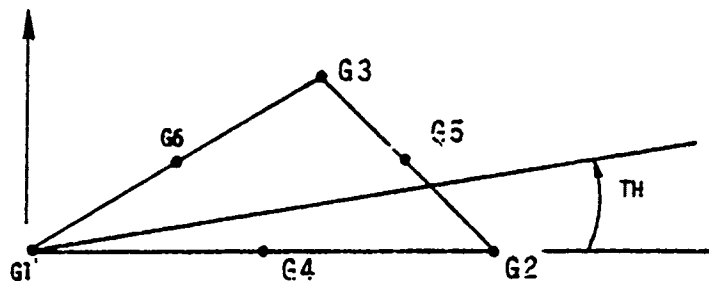
Field

Contents

EID Element identification number (Integer > 0)

PID Identification number of PTRIM6 property card.

G1,G2,G3,
G4,G5,G6 Gridpoint identification numbers of connection points (Integers > 0); $G1 \neq G2 \neq G3 \neq G4 \neq G5 \neq G6$).



- Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
 2. Interior angles must be less than 180° .
 3. The gridpoints must be ordered consecutively around the perimeter in a counter clockwise direction and starting at a vertex.
 4. The continuation card must be present.
 5. Gridpoints G2, G4 and G6 are assumed to lie at the midpoints of the sides.

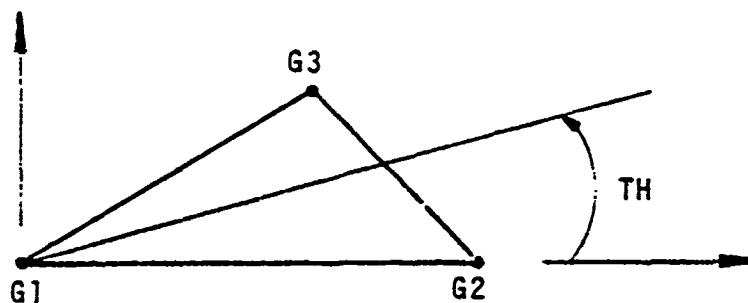
Input Data Card CTRMEM Triangular Element Connection

Description: Defines a triangular membrane element (TRMEM) of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CTRMEM	EID	PID	G1	G2	G3	TH			
CTRMEM	16	2	12	1	3	16.3			

<u>Field</u>	<u>Contents</u>
EID	Element identification number (Integer > 0)
PID	Identification number of a PTRMEM property card
G1,G2,G3	Gridpoint identification numbers of connection points (Integer > 0; G1 ≠ G2 ≠ G3)
TH	Material property orientation angle in degrees (Real) - The sketch below gives the sign convention for TH.



Remarks: 1. Element identification numbers must be unique with respect to all other element identification numbers.

Input Data Card CTUBEAM

Tubular Beam Element Connection

Description: Defines a tension-compression-torsion element (TUBE) of the structural model.

Format and Example:

1	2	3	4	5	6
CTUBEAM	EID	PID	G1	G2	G3
CTUBEAM	12	13	21	23	3

FieldContents

EID	Element identification number (Integer > 0)
PID	Identification number of a PTUBEAM property card (Default is EID) (Integer > 0)
G1, G2, G3	Gridpoint identification numbers of connection points (Integer > 0; G1 ≠ G2 ≠ G3)

Remarks:

1. Element identification numbers must be unique with respect to all other element identification numbers.
2. See Figure 3e.

Input Data Card CWEB

Shear Web Element Connection

Description: Defines a 2 node symmetric Web element (Web) of the structural model

Format and Example:

1	2	3	4	5	6	7	8	9	10
CWEB	EID	PID	G1	G2					
CWEB	4	2	1	3					

Field

EID Element identification number

PID Identification of PWEB property card

G1, G2 Gridpoint identification numbers

Remarks: 1. See Figure 3b.

Input Data Card FØRCE Static Load

Description: Defines a static load at a grid point by specifying a vector.

Format and Example:

1	2	3	4	5	6	7	8	9	10
FØRCE	SID	G		F	N1	N2	N3		
FØRCE	2	5		2.9	0.0	1.0	0.0		

<u>Field</u>	<u>Contents</u>
SID	Load set identification number (Integer > 0)
G	Gridpoint identification number (Integer > 0)
F	Scale factor (Real)
N1,N2,N3	Components of Vector

Remarks: 1. The static load applied to gridpoint G is given by

$$\vec{f} = F \vec{N}$$

where \vec{N} is the vector defined in fields 6, 7 and 8.

2. Load set is selected on the OPLOADS card.

Input Data Card GCON Generalized Constraint Components

Description: Defines the translation and rotation components of each gridpoint which are active degrees of freedom in a generalized constraint equation defined by GPCEQN cards

Format and Example:

1	2	3	4	5	6	7	8	9	10
GCON	SID	GP	$\pm U \pm V \pm W$	$\pm \theta_x \pm \theta_y \pm \theta_z$					
GCON	14	1	$+X \triangle -X$	$\triangle +X \triangle$					

Field

SID Equation identification

GP Gridpoint number

+, - Algebraic sign of component coefficient

x The x mark indicates that the component exists.

\triangle A triangle indicates that the component does not exist.

Remarks: The SID numbers on these cards appear in the GPCEQN cards which set up the constraint equation. See remarks under GPCEQN for further explanation.

Input Data Card GPCEQN Generalized Constraint Equation

Description: Defines the upper and lower limits of a generalized constraint equation. The existence of each GPCEQN card is necessary for each constraint equation.

Format and Example:

1	2	3	4	5	6	7	8	9	10
GPCEQN	SID	GCS	Upper Limit _{UL}	Lower Limit _{LL}					
GPCEQN	1	14	4.0	1.0					

Field

SID	Equation identification
GCS	Set identification of GCON cards which define the components in the equation.
UL	Upper limit of constraint equation
LL	Lower limit of constraint equation

Remarks: 1. Suppose the user wants to define the following generalized constraint equations:

$$1.0 \leq -U_1 + V_2 + 0_{x1} \leq 4.0$$

$$1.0 \leq W_2 - 0_{x4} \leq 6.0$$

The input cards would be as follows:

1	2	3	4	5
GPCEQN	1	14	4.0	1.0
GPCEQN	2	12	6.0	1.0
GCON	14	1	-X	+X
GCON	14	2	+X	
GCON	12	2	+X	
GCON	12	4		-X

Equation #1
Equation #2
-U₁, 0_{x1}
V₂
W₂
-0_{x4}

2. A generalized constraint consists of the algebraic combination of the selected degrees of freedom of all participating gridpoints and is maintained within the upper and lower limits defined for the particular group.

Input Data Card GRID Grid Point

Description: Defines the location of a geometric gridpoint of the structural model and its permanent single-point constraints.

Format and Example:

1	2	3	4	5	6	7	8	9	10
GRID	ID		X1	X2	X3		PS		
GRID	2		1.0	2.0	3.0		316		

<u>Field</u>	<u>Contents</u>
ID	Gridpoint identification number (0<Integer<999999)
X1,X2,X3	Location of the grid point.
PS	Permanent single-point constraints associated with grid-point (any of the digits 1-6 with no imbedded blanks) (Integer ≥ 0 or blank)

Remarks: 1. The coordinate system defined on all GRID cards is called the Global Coordinate System. All degrees-of-freedom, constraints, and solution vectors are expressed in the Global Coordinate System.

Input Data Card ICON

Individual Constraints

Description: Defines the constraint limits (both lower and upper) and gridpoint components which require individual constraints.

Format and Example:

1	2	3	4	5	6	7	8	9	10
ICON	Components	Lower	Upper	G ₁	G ₂	G ₃	G ₄	G ₅	
ICON	146	1.0	3.0	1	2	3	6		

Field

Components 1-6 signifies component numbers

Lower Lower limit

Upper Upper limit

G₁, G₂, G₃, etc. Gridpoint numbers. Upto 5 gridpoint numbers may appear on one ICON card.

Remarks:

- Each ICON card contains up to 5 gridpoints. When more than 5 are desired, list them on separate ICON cards.
- For example, let there be the following individual constraints:
 U₁, U₂, W₁, W₂ greater than 1.0 and less than 4.0.
 V₁, V₂, V₃ greater than 1.0 and less than 8.0.

The required ICON cards would be:

1	2	3	4	5	6	7
ICON	13	1.0	4.0	1	2	
ICON	2	1.0	8.0	1	2	3

- Rotational limits are indicated only when the beam (tube) element is used.

Input Data Card LINKS

Description: Defines element numbers which are in a "linked" group either for purposes of specifying area ratios or for buckling definitions.

Format and Example:

1	2	3	4	5	6	7	8	9	10
LINKS		BELEM	NG	BUCK	N ₁	N ₂	N ₃		
LINKS		5	3	YES	1	2	3		

Field

Contents

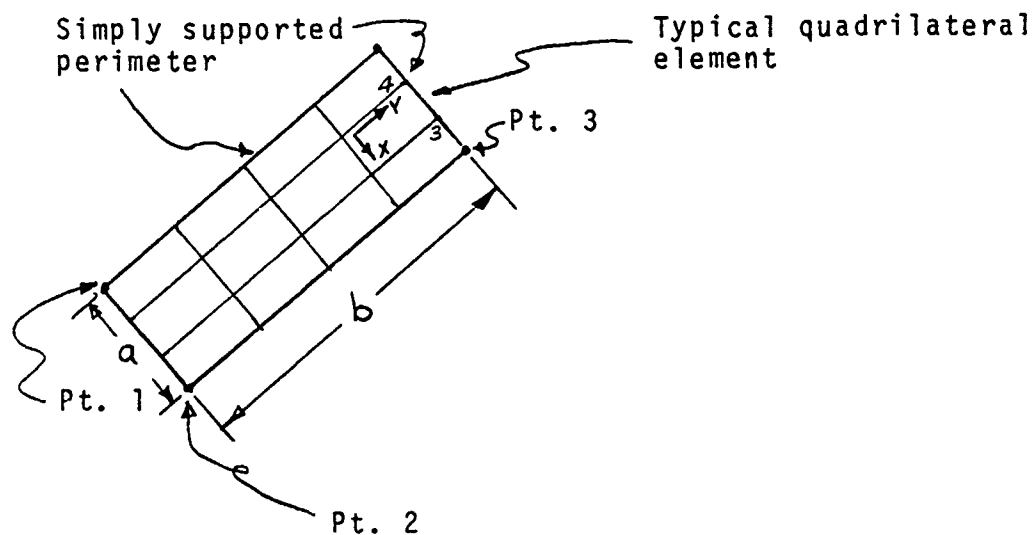
BELEM	Base element number entered in integer format
NG	Number of elements in the group. The total number of elements including the base element is entered.
BUCK	Buckling control. When "yes" is in this field, then the grouping defined is to be considered for buckling and <u>no</u> linking between design variables exist.
N ₁ ,N ₂ ,N ₃	Node points defining rectangular area.

Remarks:

1. This data is optimal.
2. The base element is the lowest numbered element in the group and it must also be the element with the smallest minimum allowable element design variable. All elements within a group are directly related to the base element through the area ratios specified on the element property cards. In other words the minimum allowable area is entered for the base element. For other members in the group the ratio (≥ 1) of member area to base element area is entered instead of an allowable. This ratio is maintained during the solution.
3. The example above indicates that elements 5, 6 and 7 belong to a linked group in which element 5 is the base element.
4. The buckling option has been included in order that a User might specify a simply supported area that is comprised of more than one element.

Remarks: (continued)

The three node point numbers are entered as fixed point numbers in order to define the rectangular simply supported region. The sketch illustrates the three points and their relationship to the contained groups of elements.



Input Data Card MØMENT Static Moment

Description: Defines a static moment at a grid point by specifying a vector.

Format and Example:

1	2	2	4	5	6	7	8	9	10
MØMENT	SID	G		M	N1	N2	N3		
MØMENT	2	5		2.9	0.0	1.0	0.0		

<u>Field</u>	<u>Contents</u>
SID	Load set identification number (Integer > 0)
G	Gridpoint identification number (Integer > 0)
M	Scale factor (Real)
N1,N2,N3	Components of Vector

Remarks: 1. The static moment applied to gridpoint G is given by

$$\vec{m} = M \cdot (N1, N2, N3)$$

2. Load set is selected on the OPLOADS card.

Input Data Card MAT1 Material Property Definition

Description: Defines the material properties for linear, temperature-independent, isotropic materials.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MAT1	MID	E	G	NU	RH0				+abc
MAT1	17	3.+7	1.9+7		4.28				ABC
+abc	SL	SU							
+BC	20.+4	15.+4							

Field

Contents

MID	Material identification number (Integer > 0)
E	Young's modulus (Real ≥ 0.0 or blank)
G	Shear modulus (Real ≥ 0.0 or blank)
NU	Poisson's ratio ($-1.0 < \text{Real} \leq 0.5$ or blank)
RH0	Mass density (Real)
SL, SU,	Lower stress limit, upper stress limit

- Remarks:
1. One of E or G must be positive (i.e., either $E > 0.0$ or $G > 0.0$ or both E and G may be > 0.0).
 2. If any one of E, G or NU is blank, it will be computed to satisfy the identity $E = 2(1+NU)G$; otherwise, values supplied by the user will be used.
 3. The material identification number must be unique for all MAT1 and MAT2 cards.

Input Data Card MAT2 Material Property Definition

Description: Defines the material properties for linear, anisotropic materials.

Format and Example: (consists of 2 cards)

1	2	3	4	5	6	7	8	9	10
MAT2	MID	G11	G12	G13	G22	G23	G33	RHO	
MAT2	13	6.2+3			6.2+3		5.1+3	0.056	
+abc						SL	SU		
+BC						20.+5			

<u>Field</u>	<u>Contents</u>
MID	Material identification number (Integer > 0)
Gij	The material property matrix (Real)
RHO	Mass density (Real)
SL, SU	Lower stress limit, upper stress limit

- Remarks:
1. The material identification numbers must be unique for all MAT1, MAT2 cards.
 2. The convention for the Gij in fields 3 through 8 is represented by the matrix relationship.

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} G_{11} & G_{12} & G_{13} \\ G_{12} & G_{22} & G_{23} \\ G_{13} & G_{23} & G_{33} \end{bmatrix} \begin{Bmatrix} \epsilon_1 \\ \epsilon_2 \\ \gamma_{12} \end{Bmatrix}$$

3. Only TRMEM and CQDMM elements may use MAT2 cards.

Input Data Card OPDVIR

Description: Defines design variables for selected elements. These design variables are used as starting guesses in an optimization run or else as specified values in a status run.

Format and Example:

1	2	3	4	5	6	7	8	9	10
OPDVIR	E1	DVAR ₁	E2	DVAR ₂	E3	DVAR ₃	E4	DVAR ₄	
OPDVIR	1	.1	3	.6	4	.50	7	.23	

Field

E1,E2...etc. Element numbers for which design variables are input.

DVAR₁, DVAR₂, etc. Design variable starting guesses for elements 1, 2, etc.

- Remarks:
1. Up to 4 elements may be defined on one OPDVIR card. More elements may be defined by successive OPDVIR cards.
 2. The use of these values is dependent on the calculation control on the OPTIM input card - field #9, OPT.
 - a. If OPT = GOPT the program will optimize using the design variable minimums input in this section as a starting guess.
 - b. If OPT = GSTA, the program will perform a statics solution using the design variables input in this section.

Input Data Card OLOADS

Description: Defines the character of the loads for optimization,
i.e., symmetric, nonsymmetric, antisymmetric.

Format and Example:

OLOADS	LOAD	NSYM	SYA	F _i	M _i	F ₂	M ₂
OLOADS	1		ANTI	5	7		

<u>Field</u>	<u>Contents</u>
LOAD	LOAD number identification (any number)
NSYM	Number of nodes on symmetric plane
SYA	SYMM - Symmetric loads ANTI - Antisymmetric loads NON - Nonsymmetric loads
F _i	SID number of FORCE cards
M _i	SID number of MOMENT cards
F ₂	required only SID number of FORCE cards
M ₂	for nonsymmetric SID number of MOMENT cards

- Remarks:
1. If F_i is present, i force cards are required.
If M_i is present, i moment cards are required.
 2. Each external load requires an OLOADS entry.

Remarks: (contd)

3. Number of Nodes on the Symmetry Plane. When a geometrically symmetric half structure is subject to antisymmetric and/or nonsymmetric loading this capability is provided wherein boundary conditions are internally defined and results are output for the entire structure. The nodes on the symmetry plane must be numbered from 1 to N and it is N that is entered here. The BOUND section must specify these nodes as free.

Input Data Card OPTIM

Description: Defines various control parameters for the OPTIM program.

Format and Example:

1	2	3	4	5	6	7	8	9	10
OPTIM	PRI	PRS	PRE	BU	MAX	CONVD	CONVW	OPT	
OPTIM	NO	YES	YES	NONE	10	.01	100.0	OPT	

Field

Contents

PRI NO/YES Print displacements every iteration

PRS NO/YES Print stresses every iteration

PRE NO/YES Print element design variables every iteration

BU NONE/ALL/SEL Buckling Anaysis SEL=SID of BUCK

MAX Maximum number iterations

CONVD Convergence criteria for design number

CONVW Convergence criteria for weight perturbations

OPT OPT Optimize using design variable on property card

GOPT Optimize using OPDVIR starting guess

GSTA Statics run using OPDVIR

STA Statics run using property card

Remarks: 1. CONVD - Convergence Criteria (Design Variable). If two successive iterations of element design variables i.e., thickness or area, meet the criteria $\left| \frac{A_n - A_{n+1}}{A_n} \right| \leq C_1$ then the iteration is stopped. C_1 is entered here.

2. CONVW - Convergence Criteria (Weight Perturbation). If two successive perturbations of the structural weight meet this criteria, then the iteration is stopped.

$$\frac{W_n - W_{n+1}}{W_n} > C_2$$

C_2 is entered here.

Input Data Card PQUAM8 MIDPOINT QUADRILATERAL MEMBRANE PROPERTY

Description: Used to define the properties of a midpoint quadrilateral membrane element. Referenced by the COUAM8 card. No bending properties are included.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PQUAM8	PID	MID	T		PID	MID	T		
PQUAM8	17	23	4.25						

<u>Field</u>	<u>Contents</u>
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
T	Membrane thickness (Real > 0.0)

Remarks:

1. All PQUAM8 cards must have unique property identification numbers.
2. One or two quadrilateral membrane properties may be defined on a single card.

Input Data Card PQDMEM1 Quadrilateral Membrane Property

Description: Used to define the properties of quadrilateral membrane. Referenced by ¹⁴ CQDMEM1 card. No bending properties are included.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PQDMEM1	PID	MID	T		PID	MID	T		
PQDMEM1	235	2	0.5						

<u>Field</u>	<u>Contents</u>
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
T	Minimum thickness of membrane (Real > 0.0)

- Remarks:
1. All PQDMEM1 cards must have unique property identification numbers.
 2. One or two quadrilateral membrane properties may be defined on a single card.

Input Data Card PRDMID

Description: Used to define the properties of a midpoint axial force member. Referenced by the CRDMID card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PRDMID	PID	MID	A		PID	MID	A		
PRDMID	24	2	.49		25	3	.60		

Field

PID Property identification number (integer > 0)
MID Material identification number (integer > 0)
A Cross sectional area (minimum)

Remarks:

1. All PRDMID must have unique property identification numbers.
2. One or two midpoint axial force member properties may be defined on a single card.

Inout Data Card PRØD Rod Property

Description: Defines the properties of a rod which is referenced by the CRØD card

Format and Example:

1	2	3	4	5	6	7	8	9	10
PRØD	PID	MID	A						
PRØD	17	23	42.6						

<u>Field</u>	<u>Contents</u>
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
A	Area of rod (Real)

Remarks:

- 1 PRØD cards must all have unique property identification numbers.
2. For structural problems, PRØD cards may only reference MAT1 material cards.

Input Data Card PSHEAR Shear Panel Property

Description: Defines the elastic properties of a shear panel.
Referenced by the CSHEAR card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PSHEAR	PID	MID	T		PID	MID	T		
PSHEAR	13	2	4.9		14	6	4.9		

<u>Field</u>	<u>Contents</u>
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
T	Minimum thickness of shear panel (Real ≠ 0.0)

- Remarks:
1. All PSHEAR cards must have unique identification numbers.
 2. PSHEAR cards may only reference MAT1 material cards.
 3. One or two shear panel properties may be defined on a single card.

Input Data Card PTRIM6 Linear Strain Midpoint Triangular
Membrane Property

Description: Defines the properties of a midpoint triangular membrane element. Referenced by the CTRIM6 card. No bending properties are included.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PTRIM6	PID	MID	T1						
PTRIM6	666	999	1.17						

Field

PID Property identification number (Integer> 0)

MID Material identification number (Integer> 0)

T1	Membrane thickness of the element (Real)
----	--

Remarks: 1. All PTRIM6 cards must have unique property identification numbers.

2. PTRIM6 cards may only reference MAT1.

Input Data Card PTRMEM Triangular Membrane Property

Description: Used to define the properties of a triangular membrane element. Referenced by the CTRMEM card. No bending properties are included.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PTRMEM	PID	MID	T		PID	MID	T		
PTRMEM	17	23	4.25						

<u>Field</u>	<u>Contents</u>
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
T	Membrane thickness (Real > 0.0)

- Remarks:
1. All PTRMEM cards must have unique property identification numbers.
 2. One or two triangular membrane properties may be defined on a single card.

Input Data Card PTUBEAM Tubular Beam Property

Description: Defines the properties of tubular beam element.
Referenced by the CTUBE card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PTUBEAM	PID	MID	TT	RAD					
PTUBEAM	2	6	6.29	0.25					

<u>Field</u>	<u>Contents</u>
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
TT	Minimum tube thickness
RAD	Radius of tube element

- Remarks:
1. PTUBE cards must all have unique property identification numbers.
 2. PTUBE cards may only reference MAT1 material cards.

Input Data Card PWEB WEB Property

Description: Used to define the properties of 2 node WEB.
Referenced by the CWEB.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PWEB	PID	MID	T		PID	MID	T		
PWEB	235	2	0.5						

<u>Field</u>	<u>Contents</u>
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
T	Thickness of the shear web (Real > 0.0)

Remarks:

1. All PWEB cards must have unique property identification numbers.
2. One or two WEB properties may be defined on a single card.

Input Data Card SPC Single-Point Constraint

Description: Defines sets of single-point constraints

Format and Example:

1	2	3	4	5	6	7	8	9	10
SPC	SID	G	C		G	C			
SPC	2	32	436		5	1			

<u>Field</u>	<u>Contents</u>
SID	Identification number of single-point constraint set (Integer > 0)
G	Grid point identification number (Integer > 0)
C	Component number (Any unique combination of the digits 1-6 (with no imbedded blanks) when point identification numbers are gridpoints).

- Remarks:
1. Single-point constraint sets must be present in the input.
 2. From one to twelve single-point constraints may be defined on a single card.
 3. SPC degrees of freedom may be redundantly specified as permanent constraints on the GRID card.
 4. The SID number should be the same on all SPC cards.

Input Data Card SPC1 Single-Point Constraint

Description: Defines sets of single-point constraints.

Format and Example:

1	2	3	4	5	6	7	8	9	10
SPC1	SID	C	G1	G2	G3	G4	G5	G6	
SPC1	3	2	1	3	10	9	6	5	

Alternate Form

SPC1	SID	C	GID1	"THRU"	GID2
SPC1	313	12456	6	THRU	32

Field

Contents

SID Identification number of single-point constraint set
(Integer > 0)

C Component number (Any unique combination of the digits
1-6 (with no imbedded blanks) when point identification
numbers are gridpoints.

G1,GID1 Grid point identification numbers (Integer > 0)

- Remarks:
1. Single-point constraint sets must be present in the input.
 2. SPC degrees of freedom may be redundantly specified as permanent constraints on the GRID card.
 3. All gridpoints referenced by G1D1 thru G1D2 must exist.
 4. No NASTRAN "continuation" cards are allowed.

Input Data Card TITLE

Title Card

Description: Information to be printed at the beginning of the computer listing.

Format and Example:

1	2	3	4	5	6	7	8	9	10
TITLE									
Plate Membrane Prob. No. 2									

Input Data Card ENDDATA

Description: Defines the end of the Data Deck

Format and Example:

1	2	3	4	5	6	7	8	9	10
ENDDATA									
ENDDATA									

- Remarks:
1. This card required even if no physical data cards exist in the deck.
 2. ENDDATA must begin in columns 1 or 2.
 3. Failure to include this card will result in an operating system termination caused by input end of file error.

V. SAMPLE PROBLEM

This sample demonstration problem, taken from Reference 1 is presented primarily to illustrate the new NASTRAN compatible data input procedure and format included in OPTIM III.

The structure selected is a symmetric wing box as shown in Figure 4. One half of the symmetric wing box is idealized and consists of 7 grid points and 16 finite elements of the following types:

- 4 axial force members
- 8 shear web elements
- 2 quadrilateral membrane elements
- 1 triangular membrane element

Gridpoints 1 and 2 are completely constrained in the x and y coordinate directions. Two load conditions are considered and they are:

1. 5,000 Lb. force at gridpoint 7 in the Z coordinate direction.
2. 10,000 Lb. force at gridpoint 7 in the x coordinate direction.

A summary of the NASTRAN compatible input data (BULK DATA) is given in Figure 5. Results of the computations performed are given in Figure 6.

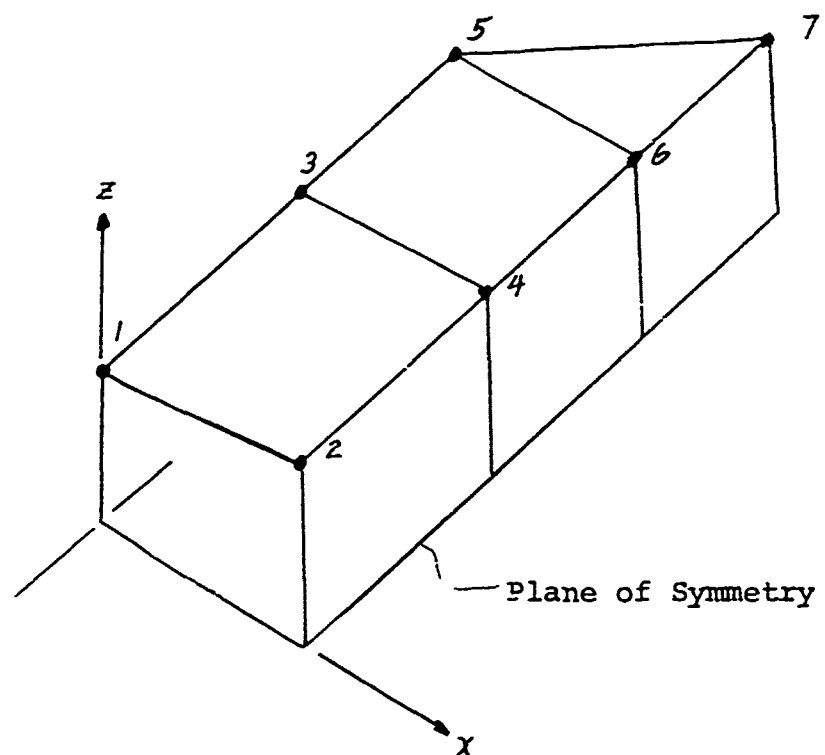


Figure 4 Wing Box

BEGIN BU	LR	SIXTEEN ELEMENT WING BOX FOR REPORT FORM INPUT AND DYNAMIC STORAGE															
TITLE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
GRID	1	0.0	0.0	10.000	0												
GRID	2	100.000	0.0	8.000	0												
GRID	3	0.0	70.000	10.000	0												
GRID	4	100.000	70.000	8.000	0												
GRID	5	C.C	140.000	10.000	0												
GRID	6	100.000	140.000	8.000	0												
GRID	7	100.000	190.000	8.000	0												
ICCN	2	-2.0000	2.0000	7	0	0	0	0	0	0	0	0	0	0	0	0	0
SPCL	1	123	1	THRU	2												
OPTIM	NO	NO	YES	NCNE	2	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000
OPLGADS	1	0	SYMM	10	0	0	0	0	0	0	0	0	0	0	0	0	0
OPLGADS	2	0	SYMM	20	0	0	0	0	0	0	0	0	0	0	0	0	0
FORCE	10	7	0.500E 04.0	0.0													
FORCE	20	7	0.100E 05.100E 01.0	0.0													
CONROD	1	1	3	28	0.100	0	0	0	0	0	0	0	0	0	0	0	0
CONROD	2	3	5	28	0.100	0	0	0	0	0	0	0	0	0	0	0	0
CGNRD	3	2	4	28	0.100	0	0	0	0	0	0	0	0	0	0	0	0
CONROD	4	4	6	28	0.100	0	0	0	0	0	0	0	0	0	0	0	0
CONROD	5	6	7	28	0.100	0	0	0	0	0	0	0	0	0	0	0	0
CWEB	6	50	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0
CWEB	7	50	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0
CWEB	8	50	5	7	0	0	0	0	0	0	0	0	0	0	0	0	0
CWEB	9	50	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0
CWEB	10	50	4	6	0	0	0	0	0	0	0	0	0	0	0	0	0
CWEB	11	50	6	7	0	0	0	0	0	0	0	0	0	0	0	0	0
CWEB	12	50	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0
CWEB	13	50	3	5	0	0	0	0	0	0	0	0	0	0	0	0	0
CTRMEN	14	43	5	6	7.0	0	0	0	0	0	0	0	0	0	0	0	0
CDMEM1	15	23	1	2	4	3	5	0	0	0	0	0	0	0	0	0	0
CDMEM1	16	33	3	4	6	5	0	0	0	0	0	0	0	0	0	0	0
PATI	28	1.0E7	3	.30	.1	0	0	0	0	0	0	0	0	0	0	0	0
PCD	-1.0E4	1.0E4															
PWEB	50	28	0.0200	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PTRMEN	43	28	0.0200	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PQMEM1	33	28	0.0200	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ENCCATA																	

Figure 5 Input Data, Sample Problem

CARD COUNT OF INPUT DATA		
	CARD TYPE	NUMBER
	BEGIN BU	1
1	TITLE	1
2	BUCK	0
3	CCNSOC	5
4	CTUEEAM	0
5	CCCMEM1	2
6	BUCK1	0
7	CQUAMB	0
8	CREMIC	0
9	CRCD	0
10	CSFEAR	0
11	CTRIM6	0
12	CTRMEM	1
13	GCCN	0
14	CWEB	8
15	ECRCE	2
16	GRIC	7
17	ICGN	1
18	LIAXS	0
19	MAT1	1
20	HGMENT	0
21	ORLOACS	2
22	GPCECN	0
23	GPCVIR	0
24	CPTIM	1
25	PGCMEM1	1
26	PRMID	0
27	PRCC	0
28	PSFEAR	0
29	PTRMEM	1
30	PTUEEAM	0
31	SPC	0
32	SPC1	0
33	SPC1	1
34	PWEB	1
35	PTRIM6	0
36	PCUAMB	0
37	ENCCATA	1
38	PTUEEAM	0
39	MAT2	0

PRINTED IN U.S.A.

0 FORMS.

Figure 6

Output, Sample Problem

NO	BEGIN BU	LK	TITLE	SIXTEEN ELEMENT WING PCX FOR REPORTS FORM INPUT AND DYNAMIC STORAGE
41	GRIC	1	C.C	0.0 10.000 0
42	GRID	2	100.C00	0.0 8.000 0
43	GRID	3	0.0 70.000	10.000 0
44	GRID	4	100.C00	70.000 8.000 0
45	GRID	5	0.0 140.000	10.000 0
46	GRID	6	100.C00	140.000 8.000 0
47	GRID	7	100.C00	190.000 8.000 0
48	ICCN	2	-2.0000	2.0000 0 0 0
49	SPL	1	123	1 1 THRU 2
50	OPTIM	NO	NO	YES NCNE 2 0.01000 0.01000 QPT
51	CPLDACS	1	0	SYMM 10 0 0
52	CPLDACS	2	0	SYMM 20 0 0
53	FORCE	10	7	0.500E 04.0 .0 .100E 01
54	FORCE	20	7	0.100E 05.100E 01.0 .0
55	CONROD	1	1	3 28 0.100 0 0 0
56	CONROD	2	3	5 28 0.100 0 0 0
57	CONROD	3	2	4 28 0.100 0 0 0
58	CONROD	4	4	6 28 0.100 0 0 0
59	CONROD	5	6	7 28 0.100 0 0 0
60	CWEB	6	50	3 4 0 0 0 0
61	CWEB	7	50	5 6 0 0 0 0
62	CWEB	8	50	5 7 0 0 0 0
63	CWEB	9	50	2 4 0 0 0 0
64	CWEB	10	50	4 6 0 0 0 0
65	CWEB	11	50	6 7 0 0 0 0
66	CWEB	12	50	3 3 0 0 0 0
67	CWEB	13	50	3 5 0 0 0 0
68	CTRMEM	14	43	5 6 7.0 0 0 0
69	CCDMEM1	15	33	1 2 4 3 0 0
70	CQCMEM1	16	33	3 4 6 5 0 0
71	MAT1	28	1.0E7	1.0E4 .1 CD
72	PWEB	50	28	0.0200 0 0 0.0
73	PTRMEM	43	28	0.0200 0 0 0.0
74	PCDMEM1	33	28	0.0200 0 0 0.0
75	ENCCATA			

Figure 6 (Continued)

INPLT PROCESSOR DIAGNOSTICS

	SECTION	MESSAGE TEST
1		
2		
3		
4	COOR	NO ERRORS DETECTED.
5		
6	ELEM	NO ERRORS DETECTED.
7		
8	OEXT	NO ERRORS DETECTED.
9		
10	BOUN	NO ERRORS DETECTED.
11		
12	OLOA	NO ERRORS DETECTED.
13		
14	ICON	NO ERRORS DETECTED.
15		
16	END	NO ERRORS DETECTED.
17		
18		
19		
20		
21		

THE COORDINATES OF THE NODE POINTS

PT	X	Y	Z
1	0.0	0.0	10.0000
2	100.0000	0.0	8.0000
3	0.0	70.0000	10.0000
4	100.0000	70.0000	8.0000
5	0.0	140.0000	10.0000
6	100.0000	140.0000	8.0000
7	100.0000	190.0000	8.0000

Figure 6 (Continued)


```

33 THE FOLLOWING NODES ARE RESTRAINED
34
35 IN THE X-DIRECTION
36 1 2
37
38 IN THE Y-DIRECTION
39 1 2
40
41 IN THE Z-DIRECTION
42 1 2
43 *** WARNING *** SYMMETRIC LOAD CONDITION 1
44 DEGREE OF FREEDOM 1 IS CONSTRAINED
45 THE C.O. LOAD IS SUPPRESSED
46 *** WARNING *** SYMMETRIC LOAD CONDITION 1
47 DEGREE OF FREEDOM 2 IS CONSTRAINED
48 THE C.O. LOAD IS SUPPRESSED
49 *** WARNING *** SYMMETRIC LOAD CONDITION 2
50 DEGREE OF FREEDOM 1 IS CONSTRAINED
51 THE C.O. LOAD IS SUPPRESSED
52 *** WARNING *** SYMMETRIC LOAD CONDITION 2
53 DEGREE OF FREEDOM 2 IS CONSTRAINED
54 THE C.O. LOAD IS SUPPRESSED
55 INCIV.DISPL.CONSTRAIN RED.DIR NOS,SYM THEN ANTISYM
56 10
57 0

```

UPPER AND LOWER DISP.CONSTRAINT LIMITS
0.200E 01

0.200E 01

```

1 THE APPLIED LOAD MATRIX
2 0.0 0.0
3 0.0 0.0
4 0.0 0.0
5 0.0 0.0
6 0.0 10000.0000
7 0.0 0.0
8 0.0 0.0
9 0.0 0.0
10 0.0 0.0
11 0.0 0.0
12 0.0 0.0
13 0.0 0.0
14 0.0 0.0
15 5000.0000 0.0

```

Figure 6 (Continued)

ITERATION 1	0.4897	0.4897	0.4897	0.4897	0.4897	0.4897
	0.0979	0.0579	0.0579	0.0979	0.0979	0.0979
THE STRUCTURE WEIGHT IS	233.4619					
ITERATION 2	0.3950	0.1625	0.4228	0.1465	0.0216	0.0243
	0.0504	0.0324	0.0674	0.0237	0.0286	0.1056
THE STRUCTURE WEIGHT IS	174.7180					

DISPLACEMENTS BY LOAD CONDITION

DISPLACEMENTS BY LOAD CONDITION			
SYMMETRIC -- LOAD CONDITION A.1		ASYMMETRIC -- LOAD CONDITION A.2	
MODE	X-COMPONENT	Y-COMPONENT	Z-COMPONENT
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	-0.3138711E-01	-0.5006377E-01	0.30002379E 00
4	-0.1367831E-02	-0.55420891E-01	0.41383725E 00
5	-0.38250275E-01	-0.5586224E-01	0.85896087E 00
6	-0.21545715E-01	-0.11656949E 00	0.13675470E 01
7	-0.10470580E 00	-0.16327555E 00	0.23638496E 01
MODE	X-COMPONENT	Y-COMPONENT	Z-COMPONENT
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.11255510E-01	-0.50709813E-02	0.40478740E-01
4	0.51333383E-02	-0.32021732E-02	-0.27189689E-01
5	0.29176056E-02	-0.13114784E-01	0.11346346E 00
6	0.15481196E-01	-0.12022015E-01	-0.10295248E 00
7	0.15481196E-01	0.12022015E-01	-0.20041879E 00

SYMMETRIC - LOAC CONDITION INC. 1

SYMMETRIC - LOAC CONDITION INC. 1

LINE	DESCRIPTION	AMOUNT	DATE	REMARKS
1	0.70581E 04			
2	-0.25419E -03			
3	0.64667E 04			
4	-0.81213E 04			
5	-0.91611E 04			
6	-0.58567E 04			
7	0.66140E 04			
8	0.0			
9	0.84544E 04			
10	0.10000E 05			
11	-0.52319E 04			
12	0.50661E 04			
13	0.60737E 04			
14	-0.23255E -04			
15	-0.25574E 04			
16	-0.14756E -04			
17	-0.5734E 03			
18	-0.64055E 03			
19	-0.80954E 04			
20	-0.11708E 04			
21	-0.88399E 04			
22	-0.85246E 04			
23	-0.17063E 04			
24	-0.43119E 04			
25	-0.24323E -04			

SYMMETRIC - LOAD CONDITION A9. 2

[illegible]

Figure 6 (Continued)

45	THE STRUCTURE WEIGHT IS				174.7180
46	REACTIONS BY LOAD CONDITION				
47	SYMMETRIC - LOAD CONDITION NO. 1				
48	NODE	X-COMPONENT	Y-COMPONENT	Z-COMPONENT	
49	1	0.13256477E 05	0.52437484E 05	-0.15400227E 04	
50	2	0.26254907E 04	0.53213336E 05	-0.34600156E 04	
51	3	0.50781250E-01	0.42961750E-01	-0.14801025E-01	
52	4	0.11718750E-01	0.50781250E-01	-0.61035156E-02	
53	5	-0.23437500E-01	0.50781250E-01	0.28076172E-01	
54	6	-0.31250000E-01	0.31640625E 00	-0.99868774E-01	
55	7	0.53791612E-01	0.51953125E 00	0.12917835E 00	
56	SYMMETRIC - LOAD CONDITION NO. 2				
57	NODE	X-COMPONENT	Y-COMPONENT	Z-COMPONENT	
	1	-0.20305934E 04	0.25862354E 03	-0.35286646E 03	
	2	-0.30502546E 04	-0.32337964E 03	0.35287183E 03	
	3	-0.78125000E-02	-0.52185059E-02	-0.53405762E-03	
	4	-0.46366719E-02	0.35062500E-02	0.27665820E-03	
1	5	-0.62011719E-01	-0.78125000E-02	0.58841705E-03	
2	6	-0.31250000E-01	0.00	0.71716309E-03	
3	7	-0.42927314E-01	-0.36987305E-01	-0.61048083E-02	
4					

Figure 6 (Continued)

VI. PROGRAMMER'S MANUAL

The programmer's manual for the OPTIM III Program is designed to facilitate its implementation, operation, modification, and extension. This manual is presented in the appendix.

VII. CONCLUSIONS

This report documents the revision and extension of the weight optimization program OPTIM II to a new program OPTIM III. The new program utilizes a NASTRAN input type format (BULK DATA DARDS) and is applicable to the analyses and optimization of complex large scale structures which contain composite membrane plate types of elements.

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APPENDIX

PROGRAMMER'S MANUAL FOR OPTIM III

Beverly J. Dale

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SECTION I

INTRODUCTION

The large scale automated minimum weight design program OPTIM II has been altered to make its input format compatible with the NASTRAN program. The resulting new program is called OPTIM III and the programming aspects are described in this Appendix.

The information presented here is geared to the Programmer. It is sufficient to fully describe the program logic and the required peripheral storage. All element generated data is stored externally to reduce core storage. A separate section is devoted to the development of these files so that I/O time may be optimized through efficient buffer description. Individual subroutine write-ups are presented along with the complete Fortran source listing.

A short description of each routine is included to aid in getting an overall familiarity with the program components. The manner of allocating storage for the stress and displacement matrices is described in diagram form.

SECTION 2

GENERAL PROGRAM LOGIC

The general organization of the "OPTIM" program is illustrated in Figures 1, 2 and 3.

The program consists of 3 principal phases:

1. Control and Data Interpretation Phase
2. Initialization Phase
3. Calculation Phase

1. Control and Data Interpretation Phase (Figure 1)

The principal purpose of this phase is to read the NASTRAN form input and prepare the information for the next two phases. Five subroutines, MAIN, SORT, ZZ, OPTIM2 and OPIMPT perform this function. The "MAIN" routine controls the program flow. The "SORT" and "ZZ" routines sort and count the data cards and then form the dynamic storage constants. Each NASTRAN label card is processed and stopped in core by "ZZ". An input file data tape based on OPTIM related input is then written. This data file is then used by "OPINPT" which writes on unit NTAPE all the data needed for initialization.

2. Initialization Phase (Figure 2)

This phase produces a variety of information for the Final Calculation Phase. Upon being activated by the "MAIN" routine, the "NEWS" routine determines the dynamic storage allocation for the Initialization Phase. The "AONE" routine is then activated and performs the following tasks:

A load matrix is generated in reduced form and written on tape NSS1.

Stiffness and stress matrices are defined by the called element routines (ELEM1 to ELEM8) and are written on tapes NSS1 and NSS2, respectively. The element routines write the number of stresses in the element and the weight of the element with a unit design variable on the tape NSS3.

A final tape, NSS4, is written with information on linked groups, stress and constraint limits and various other key control data.

3. Calculation Phase (Figure 3)

The Calculation Phase is begun by the "SIZE" routine. Upon being called by the "MAIN" routine, "SIZE" determines the dynamic storage allocation for the Incore Calculation Phase.

For the case where there is enough storage available for an incore solution then the routine "ATWO" controls the calculations. If enough storage is not available then control is passed to the "SIZE1" routine which attempts to allocate storage for an out-of-core solution. If the storage for out-of-core is adequate then the routine "ATWO1" controls the calculation. A brief description of both in-core logic and out-of-core logic follows:

In Core Logic

The routine "ATWO" controls the following functions:

A. Tapes NSS3 and NSS4 are read. These tapes are read once and the information is used to initiate the program.

B. For each iteration tapes NSS1 and NSS2 are read. The stiffness matrices are assembled in-core and then displacements are computed by the banded in-core equation solver "BANCHO". All the element stresses are computed in core and are used with the displacements by the "SCALE" routine. Scaling of the structure is done within the stress and displacement constraint limits. If buckling is specified then during the scaling process the "BUCKTB" and "IGEN2" routines are called by the "SCALE" routine. The "MODIFY" routine then adjusts element design variables by a recursive relationship using element displacements and stiffness matrices.

C. The print out of displacements, element stresses and element design variables is done by the "ATWO" routine. "ATWO" also calculates and prints the reactions after the last iteration.

Out-of-Core Logic

The routine "ATWO1" controls the following functions:

A. Tapes NSS3 and NSS4 are read and used to initialize the program. Later during execution, tape NSS3 will contain the stress matrix, one column/record. The NSS4 tape will contain the assembled stiffness matrix.

B. For each iteration tapes NSS1 and NSS2 are read. The stiffness matrices are assembled out-of-core on tape NSS4 by the "BASS" routine. Tapes NSS3 and NSS5 are used as scratch data sets for this step. The assembled stiffness matrix (which is also banded) is triangularized by routine "TCONTX" and placed on tape NSS5. Routine "EEQSX" performs the final equation solving using tape NSS5 as input. The stress matrix is computed and stored on NSS3 one column/record. The stresses and the in-core displacements are used by the "SCALE1" routine to scale the structure within stress and displacement constraint limits. If buckling is specified, the "SCALE1" routine calls

the "BUCKTB" and "IGEN2" to perform this function. As with the in-core solution, the "MODIFY" routine adjusts element design variables by a recursive relationship using element displacements and element stiffness matrices on tape NSS1.

C. The print out of displacements, element stresses and element design variables is done by the "ATW01" routine. "ATW01" also calculates and prints the reactions after the last iteration.

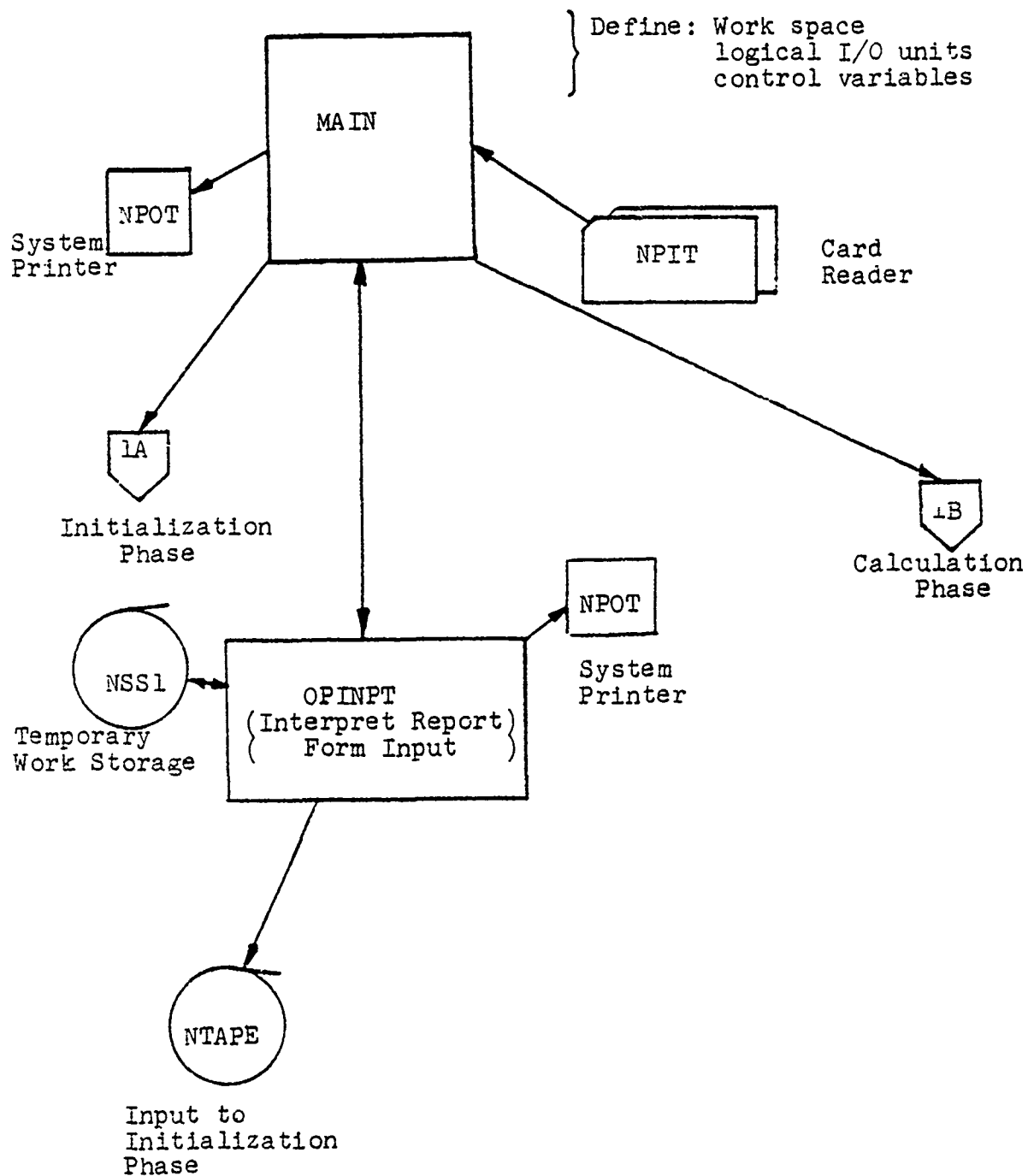


Figure 1 (Control and Data Interpretation Phase)

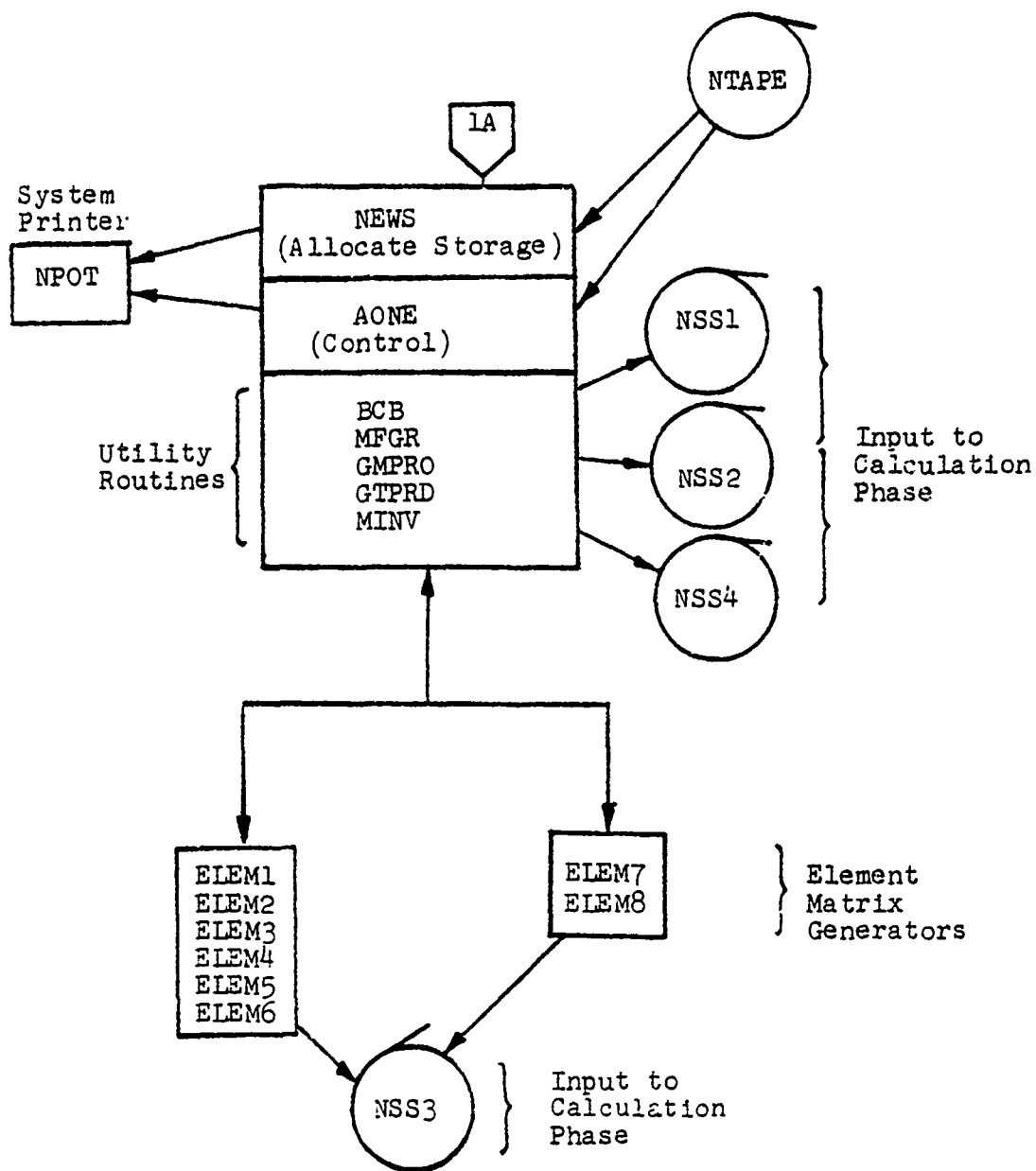


FIGURE 2 (INITIALIZATION PHASE)

SECTION 3

EXTERNAL DATA SET STRUCTURE

This program uses seven data sets during execution. The delivery version of the OPTIM program comes with the following variable names and real unit designations. These unit numbers may be redefined in the "MAIN" routine.

<u>Unit Name</u>	<u>Unit Id</u>	<u>Usage</u>
NTAPE/NSS5	8 (BINARY)	Output from "MAIN" and "OPINPT" routines and input to "AONE" routine. For out-of-core solution (Calculation Phase) this data set is called NSS5. It is next used as a scratch data set then it is used to store the triangularized stiffness matrix.
NSS1	1 (BINARY)	Contains load matrix and element stiffness matrices with assembly information
NSS2	2 (BINARY)	Contains element stress matrices.
NSS3	3 (BINARY)	ITOT (no. of elements) pairs of information from element matrix generation routines used to initialize the calculation phase. For out-of-core solution (Calculation Phase) this data set is next used as a scratch data set during stiffness matrix assembly. Finally it is used to store the stress matrix.
NSS4	4 (BINARY)	Contains initialization information for ATWO routine or ATWO1 Routine. For out-of-core solution (Calculation Phase) this data set is next used to store the banded assembled stiffness matrix.

<u>UNIT NAME</u>	<u>UNIT ID</u>	<u>USAGE</u>
L4	9 (FORMATTED)	Output from "SORT" and input to "ZZ". Contains identification record and NASTRAN input card image.
L7	7 (FORMATTED)	Output from "ZZ" and input to "OPTIM2". Contains card images in OPTIM MAGIC format.
NPIT/J5/L5	5	Standard card input (80 column card)
NPOT/JE6/J6/L6	6	Standard Line Printer (132 characters/line).

NOTE: Since units 5 and 6 are standard input and output, they will not be considered in this discussion.

NTAPE CONTENTS

OPDIVIR Section Input

For the Out-of-Core Calculation Phase. This data set is called NSS5. The triangularized stiffness matrix is stored on NSS5.

NTCDS	20A4	
RECORDS		
Title Cards		
One		
Record	((Grid (I,J), J=1, 3), I=1, N2)	
(Coordinates)		
One		
Record		
Per Element	NEL, NID, IBUCK, (NODES(J), J=1, 8), (EM(J)J=1, 7)	
ITOT		
Records		
One Record		
Linked Group	IBGP, (ILINK(LL),LL=1,IBGP)	
Bucking Info		
ONE RECORD		
Linking	(ILINK(LL),LL=1, NSG)	
Info		
One Record	(NBOUND(I), I=1,NAM)	NREACT Array number of each component bounded
Boundary Condition Info		
NNZL		
Records	IR,IC,C1,C2	
Load Components		
IF	One	(NBDF(I), I=1, NDL)
NDL.NE.0	Record	
Individual Constraint Info (ICON)		
IF	NAA	KNL, (NBDF(JK),JK=1,KNL)
NAA.NE.0	Records	
Generalized Constraint Info (GCON)		
If	One	(DISPU(I),DISPL(I),I=1,NDLL)
NAA+NDL.NE.0	Record	
IF	One	(DVJR(J),J=1,ITOT)
IRST.EQ.1	Record	
or 2		

NSSI Contents

1st Record

(DELTA(I), I=1, J1)

Load Matrix

3 Records
Per Element

J, K

(X(L), L=1, J)

Stiffness Matrix

(M(L), L=1, K), (M2(L), L=1, K), NNO, (NODES(L), L=1, NNC)

Symmetric Antisymmetric

Nodes used in
Element
Definition

Assembly info vectors

NSS2 CONTENTS

3 Records
Per Element

J, K, JK

((STR(KK, JJ), KK=1, K), JJ=1, J)

(M(L), L=1, J), (M2(L), L=1, J)

Element
Stress
Matrices

NSS3 Contents

2 Records
Per Element

LIST(I)

Number of Stresses

(PAR(L), L=KK, KK2)

Weight Info and
 $X_2 X_3$ info for element u

Purpose: Initialization of ATWO routine

For Out-Of-Core Calculation Phase

The stress matrix is stored on this data set. There is one record for each column of the stress matrix.

NSS4 Contents

NRDF, NLOAD, ITOT, NALD, NDL, NSG, NAA		Stress and Design Parameters Limits Buckling Controls
(SIGL(I), SIGU(I), ALL(I), I=1, ITOT), IBS, (IBK(I), I=1, IBS)		
(N7(I), I=1, NSG)		Linked Group Information
NRDF		No. of Reduced Deg. of Freedom
(NBDF(I), I=1, K), (NBDF2(I), I=1, K)		
(NEAA, (NE(I), I=1, NEAA), NEA2, (NE2(I), I=1, NEA2))		Generalized Constraint Info
(DISPU(I), DISPL(I), I=1, NDL)		Limits for Constraints
C1, C2, ITERN		
(AREA(I), I=1, ITOT)		
LOAD1, LOAD2, NSYM, NASYM, NONSYM, NRDF, (LNOD(I), I=1, NRDF), NRDF2, (LNOD2(I), I=1, NRDF2)		
NREF, NDOF, KKTROL, NBOU, (NPI(I), I=1, NBOU), NBOUN2, (NP2(I), I=1, NBOUN2)		

For Out-Of-Core Calculation Phase

The banded and assembled stiffness matrix is stored in this data set.

These records can be in any order on the file. It represents data in "pairs" of records. Each pair represents one specific type of data items determined by the value "NKIND" and "NCOUNT" which are written on the first record of the pair. R

Record one of the pair: NKIND, NCOUNT

Record two is determined by NKIND as shown in the following table:

NKIND	Second Record	
1	BULK	data
2	TITLE	"
3	BUCK	"
4	CONROD	"
5	CQDMEM	"
6	CQDMEM1	"
7	CQDMEM2	"
8	CQDMID	"
9	CQUAD1	"
10	CQUAD2	"
11	CRDMID	"
12	CROD	"
13	CSHEAR	"
14	CTRIA1	"
15	CTRIA2	"
16	CTRMEM	"
17	CTRMID	"
18	CTUBE	"
19	END*	"
20	ENDDATA	"
21	FORCE	"
22	GCON	"
23	GRID	"
24	ICON	"

25	LINKS	data
26	MOMENT	"
27	MAT1	"
28	OPLOAD	"
30	OPDVIR	"
31	OPTIM	"
32	PQDMEM	"
33	PQDMEM1	"
34	PQDMEM2	"
35	PQDMID	"
36	PQUAD1	"
37	PQUAD2	"
38	PRDMID	"
39	PROD	"
40	PSHEAR	"
41	PTRIA1	"
42	PTRIA2	"
43	PTRMEM	"
44	PTRMID	"
45	PTUBE	"
46	SPC	"
47	SPC1	"
48	SPC1 THRU	"
49	CWEB	"
50	PWEB	"
51	BEGIN BULK	"
52	CTRM6	"
53	CTRSHL	"
54	CQUAM8	"
55	CQUSHL	"
56	PTRIM6	"
57	PTRSHL	"
58	PQUAM8	"
59	PQUSHL	"

L7 Contents

(80 character
card images)

Record #1	REPORT (2A4)
" #2	TITLE (2A4)
" #3	NTIT (6X, 113)
" #4	(IEDINC(I), I=1, 20)
" #5	SYSTEM, (BLANK, I=1, 18)
" #6	NGR1, NGR2, NS4S, ILOAD, NECARD, MNN
" #7	OPTIM (OPT(I), I=1, 16)
" #8	COORD, (BLANK, I=1, 18)
NGRI records	{ M, C1, C2, C3
NEL records	ELEM, (BLANK, I=1, 18) { I, NOPT(I), X, NNODES(I), (NODENO(I, J), J=1, 8)
	OEXTERN, (BLANK, I=1, 18)
NECARD records	{ I, BUCK(I), A, B, C, D, E, F, G, H, P, Q, R, J, ANGLE(I)
	LINK, (BLANK, I=1, 18) LLINK
	BOUND, (BLANK, I=1, 18) (BLANK, I=1, 20) MODAL (1, I=1, NSIS)
NOCARD records	I, (LBOUND (I, J), J=1, NSYS)
NLOADS TIMES	OLOADS, (BLANK, I=1, 18) LCOND, IL
	MODAL, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
	{ IGR, C1, C2, C3, C4
NICON records	ICON, (BLANK, I=1, 19) { EYEC (J, I), J=1, 13)

NGROUP	{	GCON, (BLANK, I=1, 19)
TIMES		{ GGROUP, I
		GROUP(5, I), GROUP(6, I)
	{	GCOND (2, J), (GCOND(K, J) K=3, 14)
		. OPDVIR, (BLANK, I=1, 18)
NLL	{	OPD, (BLANK, I=1, 18)
TIMES		OPDV
last		FEND = "END"
record		

Section 4

Subroutine Write-Ups

The OPTIM program contains 37 subprograms, each with a unique sequence number. Columns 73, 74, 75 and 76 contain the "DECK" name and columns 77 through 80 contain the card sequence number for that subprogram. The first is always ----0000 with successive increments of 10.

Included with each description is a statement declaring the size of the subprogram. This number is intended as a guide only, as it reflects the storage requirement on an IBM/360/65, FORTRAN G level 19 compiler.

In this manual the subroutine writeups are presented in alphabetical order.

Brief Routine Descriptions

<u>Routine Name</u>	<u>Purpose</u>	
ADJUST	Adjust each NASTRAN form field so that it is either left or right adjusted.	
AONE	Control initialization	
ATWO	Control calculation and print out (in-core solution)	
ATWO1	Control calculation and print out (out-of-core solution)	
BANCHO	Banded in-core equation solver	
BASS	Assemble banded stiffness matrix (out-of-core solution)	
BCB	Matrix triple product	
BEQSY	Equation solver (out-of-core solution)	
BMAT	Generates A matrix for triangular plate, also area	
EUCKTB	Interfaces with SCALE and IGEN2. Determines minimum plate thickness for stability.	
CMAT3	Generates C ₃ matrix for triangular plate	
CUBIC	Solve for principle beam stresses	
EGMAT	Generates EG matrix for triangular plate	
EMAT	Generate elasticity matrix for either orthotropic or isotropic properties, membrane triangle	
ELEM1	Element Matrix Generators	Axial
ELEM2		Shear web
ELEM3		Triangle
ELEM4		Quad
ELEM5		Beam (tube)
ELEM6		Mid-point axial
ELEM7		Mid-point triangle
ELEM8		Mid-point quad

Brief Routine Descriptions (Cont'd.)

<u>Routine Name</u>	<u>Purpose</u>
ESCONT	Solve matrix equation $A^* A \text{ Transpose} * X = F$, for X (out-of-core solution)
FOMO	Process Force Cards
GMPRD	Matrix product
GTPRD	Matrix product with transpose of first matrix
IGEN2	Solves Eigenvalue for buckling coefficient of plate
INSPC	Stores data obtained from input card into working storage
INSRTI	Stores element properties and material numbers into working storage
KCALC	Solve for XK where $A * XF = F$ and A is banded <u>lower</u> triangular matrix (out-of-core solution)
KMAT	Generates stiffness matrix for triangular membrane
MAIN	Control program flow
MFGR	Matrix Ranking
MINV	Matrix Inverse
MODIFY	Next element design parameter guess after scaling
NEWS	Allocate storage for initialization
OPTIM2	Interprets input and initializes data.
OPINPT	Interpret report from input and place results on NTAPE
PS3D	Define cubic equation from beam stress components
PS3R	Normalize stresses
READI	Reads and modifies input data
SCALE	Scale structure using stress, displacement and buckling constraints (in-core solution)
SCALE1	Scale structure using stress, displacement and buckling constraints (out-of-core solution)
SIZE	Allocate storage for calculation phase (in-core solution)

Brief Routine Descriptions (Cont'd)

<u>Routine Name</u>	<u>Purpose</u>
SIZEL	Allocate storage for calculation phase (out-of-core solution)
SMAT	Generate stress element matrix for membrane triangular plate with orthotropic properties
SORT	Sort and count data based on LABEL information
SPCSUB	Process SPC (single point constraint) cards
TCONTX	Control tape flow to triangularize stiffness matrix (out-of-core solution)
TMAT	Generate transformation matrix for triangular plate orthotropic angle
TTRI	Triangularize rows of a banded matrix A (out-of-core solution)
WRITEL	Tests character of element connection card and writes element information on to file
XCALK	Solve for X where $A * X = XK$ and A is an <u>upper</u> triangular matrix
XTRAK	Interpret degree of freedom informations
XTRAK2	Interpret degree of freedom informations for generalized constraint information
ZZ	Generates OPTIM data which is input by NASTRAN form input cards

- | | |
|---------------------|---|
| 1. Subroutine Name | ADJUST |
| 2. Purpose | Adjust each NASTRAN form field so that it is either left or right adjusted. |
| 3. Procedures | Each character of the word is tested to see if it is blank. When a non-blank is met, it is shifted to the end of the word. |
| 4. Input Arguments | <p>WORD - Input word to be either right or left adjusted</p> <p>Icode Icode = 8 specifies that the word should be right adjusted</p> <p>Icode = 1 specifies that the word should be left adjusted</p> |
| 5. Output Arguments | Word right adjusted, word is stored back into WORD |
| 6. Error Returns | None |
| 7. Calling Sequence | CALL ADJUST (Word, ICODE) |
| 8. Subroutine User | NEWS |

1. Subroutine Name: AONE
2. Purpose: Assemble all initialization information for the calculation phase of the program.
3. Equations and Procedures:
 - a) Print out title cards.
 - b) Retrieve (I5) coordinate+element data. If requested print this data out.
 - c) Recalculate boundary conditions if symmetry plane nodes are specified.
 - d) Create load matrix from input loads.
 - e) Define virtual loads for individual constraints and generalized constraints.
 - f) Call element routines.
 - g) Four tapes of data are written with information for the calculation program (ATWO).

4. Input Arguments:

I5	(Unit 8) tape
NPOT	(Unit 6) printer
NSS1-NSS4	(Units 1-4) tapes
N2	No. of nodes
NAA	No. of generalized constraints
NDL	No. of Individual Constraints
NSG	No. of Linked Groups
NNZL	No. of input loads
KLN2	No. of symmetry plane nodes
NSYM	No. of symmetric load conditions
NASYM	No. of antisymmetric load conditions
NONSYM	No. of non-symmetric load conditions
ITERN	Max. no. of iterations
NTCDS	No. of title cards

5. Output Arguments:

C1INP)	Convergence limits
C2INP)	
NRDF	No. of reduced DOF (symmetric load condition)
NEAA	No. of generalized displacement constraints
NBOU	Total no. of constrained DOF (symmetric load condition)
IRST	Calculation control

6. Error Returns: IER

7. Calling Sequence:

CALL AONE(X,Y,Z,N5,N6,N7,E,AMU,N8,N17,ALL,RHO,SIGU,
SIGL,R,N11,N13,N15,NOAL,NOAL2,KL,KL2,LNOD,LNOD2,
DISPU,DISPL,NBDF,NBDF2,NSE,DELTA,I5,NPOT,NSS1,NSS2,
NSS3,NSS4,IBUKL,IELT,IBK,N1,N2,NAA,NDL,NSG,NNZL,

NALD, KLN2, NSYM, NASYM, NONSYM, ITERN, NTCDS, IREST, ITOT,
IELI, NREACT, C1INP, C2INP, NRDF, NRDF2, NEAA, NEA2, NDL1,
NDL2, NBOU, NBOUN2, IRST, KNCAL, IER)

8. Input Tapes: NTAPE (unit 8)

9. Output Tapes:

NSS1 (unit 1)
NSS2 (unit 2)
NSS3 (unit 3)
NSS4 (unit 4)

10. Scratch Tapes: None

11. Storage Required: (20160 bytes) 5040 words

12. Subroutine User: NEWS

13. Subroutine Required:

ELEM1
ELEM2
ELEM3
ELEM4
ELEM5
ELEM6
ELEM7
ELEM8

14. Remarks: None

1. Subroutine Name: ATWO
2. Purpose: Control execution of the in-core calculation phase of the program.
3. Equations and Procedures:
 - a. Read in all data from NSS4 tape.
 - b. Generate information vectors for BANCHO (in-core equation solver).
 - c. Read in data from NSS3. Element information consisting of number of stresses and weight factor.
 - d. Assemble stiffness matrices and solve for stresses and displacements in two passes. The first pass computes symmetric load conditions and the second pass computes anti-symmetric load conditions.
 - e. If this is a statics problem go to g) otherwise continue.
 - f. Call SCALE routine to scale stresses, displacements and design variables.
 - g. Print design parameters, displacements and stresses if requested for every iteration or if this is last iteration. If statics run go to j).
 - h. Check convergence.
 - i. Call MODIFY routine and return to d).
 - j. If last iteration compute and print reactions by load and node.

4. Input Arguments:

LLK	Total number of stresses
NPOT	(Unit 6) printer
NSS1-NSS4	(Units 1-4) tapes
NGV	Calculation control
NTERN	Maximum number of iterations
IP1	Print control for displacements
IP2	Print control for stresses
IPRINT	Print control for element design variables
IBUKL	Buckling control from OPTIM section of input

5. Output Arguments: None

6. Error Returns: IER

7. Calling Sequence:

CALL ATWO(N7,SIGL,SIGU,ALL,LIST,AREA,AQEA,BIGS,PAR,DELTA,
STRESS,NE,NE2,DISPU,DISPL,NEDF,NEDF2,LNOD,LA,LR,AUX,
N2,LA2,LNOD2,ST,NP1,NP2,ADFA,N5,N6,AREAD,LLK,NPOT,NSS1,
NSS2,NSS3,NSS4,IP1,IP2,NGV,NTERN,IPRINT,IBUKL,IBK,IER)

8. Input Tapes:

NSS1	(Unit 1)
NSS2	(Unit 2)
NSS3	(unit 3)
NSS4	(Unit 4)

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required:

(14032 Bytes) 3508 words

12. Subroutine User: Size

13. Subroutine Required:

BANCHO
SCALE
MODIFY

14. Remarks: None

1. Subroutine Name: ATW01
2. Purpose: Control execution of the out-of-core calculation phase of the program.
3. Equations and Procedures:

The difference between the ATW0 and ATW01 routines is that the stress matrix is stored on tape and the assembled stiffness matrix is also on tape for the ATW01 routine.

- a) Read in all data from NSS4 tape.
- b) Read data from NSS3 tape.
- c) Assemble stiffness matrices and solve for displacements and stresses in two passes. The first pass solves for symmetric load conditions and the second pass solves for anti-symmetric load conditions. Call routines BASS, BEQSX AND TCONTX to assemble and solve for displacements.
- d) Go to f) for statics problem.
- e) Call SCALE1 routine to scale stresses, displacements and design variables.
- f) Print design variables, displacements and stresses if requested for every iteration or if this is the last iteration. If statics run go to i).
- g) Check convergence.
- h) Call MODIFY routine and return to c).
- i) If last iteration compute and print reactions by load and node.

4. Input Arguments:

LLK	Total number of stresses
NPOT	Printer
NSS1-NSS5	Tape Units
NGV	Calculation control
NTERN	Maximum number of iterations
IP1,IP2,}	Print controls for displacement stress+
IPRINT }	element design variables, respectively
IBUCL	Buckling control from OPTIM section of input

5. Output Arguments: None
6. Error Returns: None
7. Calling Sequence:

CALL ATW01 (N7,SIGL,SIGU,ALL,LIST,AREA,AQEA,BIGS,PAR,DELTA,STRESS,NE,NE2,DISPU,DISPL,NBDF,NBDF2,LA,NZ,INOD2,ST,NP1,NP2,ADEA,N5,N6,AREAD,LLK,NPOT,NSS1,NSS2,NSS3,NSS4,NSS5,IP1,IP2,NGV,NTERN,IPRINT,IBUCL,IBK,NTOTAL,IER).

8. Input Tapes:

NSS1
NSS2
NSS3
NSS4
NSS5

9. Output Tapes: None

10. Scratch Tapes: NS

11. Storage Required:

(14978 Bytes) 3745 words

12. Subroutine User: SIZE1

13. Subroutine Required:

BASS
SCALE1
MODIFY
BEQ SX
TCONTX

1. Subroutine Name: BANCHO
2. Purpose:
In core banded matrix equation solver.
3. Equations and Procedures:
When given an NbyN positive definite matrix [A] a general Cholesky triangularization is effected.
4. Input Arguments:
A Matrix of coefficients
R Independent variable (vectors)
N Number of equations
M Number of dependent variables for solution
IR Row numbers
IC Column number of first non-zero term in A (for each row).
IA Diagonal locations in A
AUX Dummy array (N long)
5. Output Arguments:
R Solution vectors
A Is destroyed
6. Error Returns:
Writes matrix can not be inverted, ROW, I4, STOP
7. Calling Sequence:
CALL BANCHO (A,R,N,M,IR,IC,IA,AUX)
8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required:
(4358 Bytes) 1089 words
12. Subroutine User: ATWO
13. Subroutine Required: None

1. Subroutine Name: BASS
2. Purpose:
Assembly of banded symmetric matrix from symmetric element arrays.
3. Equations and Procedures:
 - a) The total assembled matrix is initially set = zero.
 - b) A "core full" section of the assembled matrix is handled at one time. Each element matrix is read into STA from tape I4. Each LISTEL is read from tape I4.- This LISTEL is an element matrix array which contains the row numbers of the assembled matrix into which the element matrix must be added.
 - c) Each fixed point number in LISTEL is examined. If it is = 0 no addition into the system matrix is made. If it is greater than the maximum row number considered in the current computation pass, the particular element information is put on Tape I8 for later use in a subsequent computation pass.
 - d) If more than one computation pass is necessary, the section of the element matrix which has not been used is placed on tape I3.
 - e) Steps 2, 3, 4, are repeated for each element.
 - f) The assembled matrix portion for each computation pass is placed on tape I3 in banded form. Each row of the matrix constitutes a record.

4. Input Arguments:

STA	Storage array for assembled matrix
NELEM	Number of elements
NMDB	Order of system
LISTEL	Element of assembly vector
NZEL	Cumulative total of non zero elements in rows 1 through i-1 or reduced matrix
IZR	Number of zero elements in row of reduced matrix
IRA	Work storage array
IMAX	Number of work storages available
ST	Storage array for element stiffness matrix
AREA	Element design parameter array
KASEM	Symmetric/anti-symmetric indicator

5. Output Arguments:

N5	Output element array read from tape I4
N6	Output element array read from tape I4
BIGS	Output element array read from tape I4

6. Error Returns: None

7. Calling Sequence:

CALL BASS (STA, NELEM, NMDB, LISTEL, NZEL, IZR, IRA, IMAX,
ST, I4, I8, I3, I7, AREA, KASEM, N5, N6, BIGS).

8. Input Tapes:

Tape I4 - Element matrices and element controls

9. Output Tapes:

Tape I3 - Assembled matrix in banded symmetric form.
Each row equals a record.

10. Scratch Tapes:

I7 - Temporary storage for element matrices
I8 - First temporary storage for element matrices
for later computation pass

11. Storage Required:

(3456 Bytes) 864 words

12. Subroutine User: ATWO1

13. Subroutine Required: None

1. Subroutine Name: BCB
2. Purpose: To evaluate the triple product: the transpose of a matrix A, a symmetric matrix S and the A matrix
3. Equations and Procedures:

$$AN_{MM} = \sum_N \sum_N^T A_{MN} * S_{NN} * A_{NM}$$
4. Input Arguments:

A	The elements of the A matrix
SYM	The elements of the S matrix (symmetric-bottom half)
ND,MD	Dimension of A matrix
N, M	Order of A matrix
N1	Number of rows to be deleted in multiplication = 0
SCAL	Scalar quantity
IASSY	See remark
5. Output Arguments:

AN:	Elements of the matrix AN which is the final product
-----	--
6. Error Returns: None
7. Calling Sequence:
 CALL BCB(A,SYM,AN,ND,MD,N,M,N1,SCAL,IASSY)
8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required:
 (1040 bytes) 260 words
12. Subroutine User:
 ELEM7, ELEM4, ELEM5
13. Subroutine Required: None
14. Remarks:
 IASSY controls the summation procedure.
 If = 1, AN will be the sum of the calculated AN and all previous elements of AN.
 =0, AN will be the triple product.

1. Subroutine Name: BEQSX

2. Purpose:

To perform simultaneous equation solution for banded symmetric matrix input using Cholesky procedure.

3. Equations and Procedures:

1. The program is designed so that a "core-filled" piece is considered at one time. The procedure to handle this is set up.
2. All loads are stored in pcol from the input argument list.
3. A call to ESCONT is made. This is the routine which actually does the computation.
4. Displacements are stored in the DISPL array output from ESCONT.

4. Input Arguments:

AK	Storage array for input matrix
NZEL	Cumulative total of non-zero elements in rows 1 through i-1 of reduced matrix
IZR	Number of zero elements in row of reduced matrix
XK	Working storage array
PCOL	Load vector
NMDB	Order of system
NTOTAL	No. of work storages available
NL	No. of load conditions

5. Output Arguments:

DISPL - Displacements

6. Error Returns: None

7. Calling Sequence:

CALL BEQSX (AK,NZEL,IZR,XK,DISPL,PCOL,I7,NMDB, NTOTAL,NL)

8. Input Tapes:

I7 - Input triangularized banded matrix array

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required:

(1864 Bytes) 466 words

12. Subroutine User: ATW01

13. Subroutine Required: ESCONT

1. Subroutine NAME: BMAT
2. Purpose Generates A matrix for triangular plate. Also generates AREA of triangle.

3. Equation and Procedures

$$\text{BINV} = \frac{\begin{vmatrix} x_2y_3 - x_3y_2 & 0 & 0 \\ y_2 - y_3 & y_3 & -y_2 \\ x_3 - x_2 & -x_3 & x_2 \end{vmatrix}}{x_2y_3 - x_3y_2}$$

$$\text{Area} = \frac{1}{2} (x_1y_2 + x_2y_3 + x_3y_1 - y_3x_1 - x_3y_2 - x_2y_1)$$

4. Input Arguments

$x(i)$	x coordinate values	}	$i = 1, 2, 3$
$y(i)$	y coordinate values		
5. Output Arguments

BINV	output matrix
AREA	output value of area
6. Error Returns None
7. Calling Sequence CALL BMAT (BINV, X, Y, AREA)
8. Subroutine User ORTHO3
9. Subroutine Required None

1. Subroutine Name: BUCKTB

2. Purpose:

This subroutine will determine the minimum plate thickness for the stability of a flat rectangular simply supported plate subjected to biaxial stresses and shear.

3. Equations and Procedures:

The Shear Buckling Coefficient, K_s , is determined for symmetric and antisymmetric buckling modes wherein the eigenvalue subroutine IGEN2 is employed. A one dimensional Newton Raphson iterative procedure is used to converge the K_s calculated and the K_s determined from the element geometry and state of Stress. The solution is based on the Raleigh-Ritz method and the general form assumed for the deflected surface is

$$W = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} A_{mn} \sin \frac{m\pi x}{a} \sin \frac{n\pi y}{b}$$

K_s is calculated from the homogeneous linear set of equations represented as

$$\sum_p \sum_q \frac{mnpq}{(m^2-p^2)(n^2-q^2)} a_{pq} = \frac{-\pi^2}{32K_s\beta^3} \left[(m^2+n^2\beta^2)^2 - K_x m^2\beta^2 - K_y n^2\beta^4 \right] a_m$$

where $\beta = a/b$; $m=1, 2, 3 \dots$; $n = 1, 2, 3 \dots$; and

$(m \mp p, n \mp q)$ are odd numbers.

4. Input Arguments:

SIGX	Stress in the x direction
SIGY	Stress in the y direction
TAU	Shear stress in x-y plane
T0	Given thickness
AL, BL	Lengths of sides of rectangle AL BL
DC	Input material constant
IELE	Element number

5. Output Arguments:

TB - Output material thickness

6. Calling Sequence:

CALL BUCKTB(SIGX,SIGY,TAU,TO,AL,BL,DC,IELE,IOP,TB)

7. Input Tapes: None

8. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required:

(9880 Bytes) 2470 words

12. Subroutine User: SCALE

13. Subroutine Required: IGEN2

1. Subroutine NAME CMAT3
2. Purpose Generates C_3 matrix for triangular plate
3. Equations and
 Procedures $C_3 = T * Eg * T^T$

 $T = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}$
4. Input Arguments EG 3 x 3 material elasticity matrix
5. Output Arguments C_3 Matrix defined by equation above
6. Error Return: None
7. Calling Sequence CALL CMAT3 (C_{3_1} EG)
8. Subroutine User ORTHO3

1. Subroutine Name: CUBIC
2. Purpose:
To determine principle stresses for the tube (beam) element.
3. Equations and Procedures:
Where X is the stress given
$$x^3 + Ax^2 + Bx + C = 0$$

Solve the cubic equation and return the three roots.
4. Input Arguments:
A, B, C - Coefficients of cubic equation
XX - Proportionality factor
5. Output Arguments:
A,B,C - Three unequal real roots
6. Error Returns: None
7. Calling Sequence: CALL CUBIC (A,B,C,XX)
8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required:
(1748 Bytes) 437 words
12. Subroutine User: PS3D
13. Subroutine Required: None
14. Remarks: None

- | | |
|----------------------------|---|
| 1. Subroutine Name | EGMAT |
| 2. Purpose | Generate Eg matrix for triangular plate |
| 3. Equation and Procedures | $Eg = TET^T$ |
| 4. Input Argument | E = 3 x 3 matrix
T = 3 x 3 transformation matrix |
| 5. Out Arguments | Eg = matrix defined by equations above |
| 6. Error Returns | None |
| 7. Calling Sequence | Call EGMAT (EG, E, T) |
| 8. Subroutine User | ORTH03 |

1. Subroutine Name EMAT
2. Purpose To generate elasticity matrix for either orthotropic or isotropic properties
3. Equations and Procedures Orthotropic $E = \begin{vmatrix} G_{11} & G_{12} & G_{13} \\ G_{21} & G_{22} & G_{23} \\ G_{31} & G_{32} & G_{33} \end{vmatrix}$
 (IMAT = 2)
- Isotropic $E = \begin{vmatrix} E_x & \mu_{xy} & 0 \\ \mu_{xy} E_y & E_y & 0 \\ 0 & 0 & G_{xy} \end{vmatrix}$
 (IMAT = 1)
4. Input Arguments $E_x, E_y, \mu_{xy}, G_{xy}$ - material properties

 EM - contains G_{ij} values
 IMAT - Orthotropy code = 2 orthotropic
 Orthotropy code = 1 isotropic
5. Output Arguments E - output 3 x 3 matrix defined by equations above
6. Error Returns None
7. Calling Sequence Call EMAT ($E_x, E_y, \mu_{xy}, G_{xy}, E, EM, IMAT$)
8. Subroutine User

1. Subroutine Name: ELEM1

2. Purpose:

To compute the elemental stress and stiffness matrices for an axial element.

3. Input Arguments:

X, Y, Z	Node point coordinates
E	Modulus of elasticity
AMU	Poisson's ratio
RHO	Density
N5, N6	Element nodes
NEL	Element number
N1	Degrees of freedom/node
N2	Total number of nodes

4. Output Arguments:

M	Unreduced direction numbers for degrees of freedom of element
M(25)	Order of stiffness matrix
M(26)=1	Number of stress components (tape NSS3)
ST(1)	Start of stiffness matrix
ST(301)	Start of stress matrix
AK(1)	(on tape NSS3) weight of element with unit design variable

5. Error Returns: None

6. Calling Sequence:

CALL ELEM1 (X, Y, Z, E, AMU, RHO, N7, N5, N6, N8, N9, N10, N11, N12, R, M, NEL, N1, N2)

7. Input Tapes: None

8. Output Tapes: NSS3

9. Scratch Tapes: None

10. Storage Required:

(1789 Bytes) 445 words

11. Subroutine User: AONE

12. Subroutine Required: None

13. Remarks:

The stress matrix provides one stress component, σ_x .

1. Subroutine Name: ELEM2

2. Purpose:

To compute the element stress and stiffness matrices for a shear web element.

3. Input Arguments:

X,Y,Z	Node point coordinates
E	Modulus of Elasticity
AMU	Poisson's Ratio
RHO	Element Density
N5,N6,N7,N8	Element nodes
NEL	Element number
N1	Degrees of freedom/node
N2	Total number of nodes

4. Output Arguments:

MM	Unreduced direction numbers for degrees of freedom element
MM(25)	Order of stiffness matrix
MM(26)=1	Number of stress components (on tape NSS3)
ST(1)	Start of stiffness matrix
ST(301)	Start of stress matrix
ARG1	(On tape NSS3) weight of element with unit design variable

5. Error Returns: None

6. Calling Sequence:

CALL ELEM2 (X,Y,Z,E,AMU,RHO,N7,N5,N6,N8,N9,N10,N11,N12,
R,MM,NEL,N1,N2)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

10. Storage Required:

(7246 Bytes) 1811 words

11. Subroutine User: AONE

12. Subroutine Required: None

13. Remarks:

- A. This element can be defined by 2 or 4 nodes.
- B. The stress matrix provides one stress component, γ_{xy} .

1. Subroutine Name: ELEM3

2. Purpose:

To compute the element stress and stiffness orthotropic matrices for a triangular plate element, with properties and material angle variation.

3. Input Arguments:

X, Y, Z	Node point coordinates
E	Modulus of elasticity
AMU	Poisson's ratio
RHO	Density
N5, N6, N7	Element nodes
NEL	Element number
N1	Degrees of freedom/node
N2	Total number of nodes
EM	Material properties
IMAT	Orthotropic code
ANGLE	Material angle

4. Output Arguments:

M	Reduced direction number for degrees of freedom of element
M(25)	Order of stiffness matrix
M(26)=3	Number of stress components (on tape NSS3)
ST(1)	Start of stiffness matrix
ST(301)	Start of stress matrix
AREA	(On tape NSS3) weight of element with unit design variable

5. Error Returns: None

6. Calling Sequence:

CALL ELEM3 (X, Y, X, E, AMU, RHO, N7, N5, N6, N8, N9, N10, N11, N12, R, M, NEL, N1, N2, GM, IMAT, ANGLE)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

- 10. Storage Required: (4876 Bytes) 1219 words
- 11. Subroutine User: AONE
- 12. Subroutine Required: ORTH03
- 13. Remarks:

Three components of stress at the midpoint are provided.
These stresses are σ_x , σ_y , τ_{xy} .

1. Subroutine Name: ELEM4

2. Purpose:

This routine computes the element stress and stiffness matrices for a quadrilateral plate element.

3. Input Arguments:

X,Y,Z	Node point coordinates
E	Modulus of elasticity
AMU	Poisson's ratio
RHO	Density
N5, N6,) N7, N8)	Element nodes
NEL	Element number
N1	Degrees of Freedom/node
N2	Total number of nodes

4. Output Arguments:

M	Unreduced direction numbers for degrees of freedom of element
M(25)	Order of stiffness matrix
M(26)=7	Number of stress components (on tape NSS3)
ST(1)	Start of stiffness matrix
ST(301)	Start of stress matrix
ARG1	(On tape NSS3) weight of element with unit design variable
X_2/X_3	Ratio (on tape NSS3) used in SCALE routine

5. Error Returns: None

6. Calling Sequence:

CALL ELEM4 (X,Y,Z,E,AMU,RHO,N7,N5,N6,N8,N9,N10,N11,
N12,R,M,NEL,N1,N2)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

10. Storage Required: (6544 Bytes) 1636 words

11. Subroutine User: AONE

12. Subroutine Required: MINV
BCB

13. Remarks: Seven components of stress are defined. These stresses are:

$\sigma_{x1}, \sigma_y, \sigma_{x3}, \sigma_{y3}, \sigma_{xm}, \sigma_{ym}, \tau_{xy_m}$ (M-indicates midpoint)

1. Subroutine Name: ELEM5

2. Purpose:

This subroutine computes the element stress and stiffness matrices for a beam (tube) element.

3. Input Arguments:

X,Y,Z	Node point coordinates
E	Modulus of elasticity
AMU	Poisson's ratio
RHO	Density
N5,N6,N7	Element nodes
NEL	Element number
N1	Degrees of freedom/node
N2	Total number of nodes

4. Output Arguments:

M	Unreduced direction numbers for degrees of freedom of element
M(25)	Order of stiffness matrix
M(26)=6	No. of stress components (on tape NSS3)
ST(1)	Start of stiffness matrix
ST(301)	Start of stress matrix
ARG1	(On tape NSS3) weight of element with unit design variable

5. Error Returns: None

6. Calling Sequence:

CALL ELEM5 (X,Y,Z,E,AMU,RHO,N7,N5,N6,N8,N9,N10,N11,N12,R,M,NEL,N1,N2)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

10. Storage Required: (4466 Bytes) 1116 words

11. Subroutine User: AONE $\sqrt{6}$

12. Subroutine Required: BCB

13. Remarks:

Six stresses are available from the stress matrix. These stresses are

$\sigma_x, \tau_{yz}, \sigma_{my_1}, \sigma_{my_2}, \sigma_{mz_1}, \sigma_{mz_2}$.

1. Subroutine Name: ELEM6

2. Purpose:

This subroutine computes the element stress and stiffness matrices for an axial element with a mid-point node.

3. Input Arguments:

X,Y,Z	Node point coordinates
E	Modulus of elasticity
AMU	Poisson's ratio
RHO	Density
N5,N6,N7	Element nodes N7 (NEL) is the midpoint node
NEL	Element number
N1	Degrees of freedom/node
N2	Total number of nodes

4. Output Arguments:

M	Unreduced direction numbers for degrees of freedom of element
M(25)	Order of stiffness matrix
M(26)=2	No. of stress components (on tape NSS3)
ST(1)	Start of stiffness matrix
ST(301)	Start of stress matrix
WT	(On tape NSS3) weight of element with unit design variable

5. Error Returns: None

6. Calling Sequence:

CALL ELEM6 (X,Y,Z,E,AMU,RHO,N7,N5,N6,N8,N9,N10,N11,
N12,R,M,NEL, N1,N2)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

10. Storage Required: (267⁴ Bytes) 669 words

11. Subroutine User: AONE

12. Subroutine Required: None

13. Remarks:

A. Two stress components are provided by the stress matrix. These stresses are: σx_1 and σx_2 .

B. The coordinates for the mid-point node are computed in the routine.

1. Subroutine Name: ELEM7

2. Purpose:

This subroutine computes the element stress and stiffness matrices for a triangular plate element with midpoint nodes.

3. Input Arguments:

X,Y,Z	Node point coordinates
E	Modulus of elasticity
AMU	Poisson's ratio
RHO	Density
N5,N6,N7 N8,N9,N10	Element nodes
NEL	Element no.
N1	Degrees of freedom/node
N2	Total no. of nodes

4. Output Arguments:

M	Unreduced direction numbers for degrees of freedom of element
M(25)	Order of stiffness matrix
M(26)=12	No. of stress components (on Tape NSS3)
ST(1)	Start of stiffness matrix
ST(301)	Start of stress matrix
WT	(On tape NSS3) weight of element with unit design variable

5. Error Returns: None

6. Calling Sequence:

CALL ELEM7 (X,Y,Z,E,AMU,RHO,N7,N5,N6,N8,N9,N10,N11,
N12,R,M,NEL,N1,N2)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

10. Storage Required: (8022 Bytes) 2006 words

11. Subroutine User: AONE

12. Subroutine Required: MINV
BCB

13. Remarks:

- A. Twelve components of stress are provided by the stress matrix. These stresses are:

$$\sigma_{x_1}, \sigma_{y_1}, \tau_{xy_1}, \sigma_{x_2}, \sigma_{y_2}, \tau_{xy_2}, \sigma_{x_3}, \sigma_{y_3}, \tau_{xy_3},$$

$$\sigma_{x_m}, \sigma_{y_m}, \tau_{xy_m}$$

where m - denotes the centroid of the element.

- B. Coordinates of the midpoint nodes are computed in the routine.

1. Subroutine Name: ELEM8

2. Purpose:

This subroutine computes the element stress and stiffness matrices for a quadrilateral plate element with midpoint nodes.

3. Input Arguments:

XC,YC,ZC	Node point coordinates
E	Modulus of elasticity
AMU	Poisson's ratio
RHO	Density
N5,N6,N7 N8,N9,N10 N11,N12	} Element nodes
NEL	
N1	
N2	Element no.
N1	Degrees of freedom/node
N2	Total no. of nodes

4. Output Arguments:

M	Unreduced direction numbers for degrees of
M(25)	Order of stiffness matrix
M(26)=15	No. of stress components (on tape NSS3)
ST(1)	Start of stiffness matrix
ST(301)	Start of stress matrix
WT	(On tape NSS3) weight of element with unit design variable

5. Error Returns:

If the ranking routine MFGR outputs a rank not equal to 16, there will be a print out (B matrix error). This will usually be due to a program input error.

6. Calling Sequence:

CALL ELEM8 (XC,YC,ZC,E,AMU,RHO,N7,N5,N6,N8,N9,N10,
N11,N12,R,M,NEL,N1,N2)

7. Input Tapes: None

8. Output Tapes: NSS3 (Unit 3)

9. Scratch Tapes: None

10. Storage Required: (31162 Bytes) 7791 words

11. Subroutine User: AONE

12. Subroutine Required:

MFGR
MINV
GMFRD
GTPRD
ECB

13. Remarks:

- A. Fifteen stress components are provided by the stress matrix. These are:

$\sigma_{x_1}, \sigma_{y_1}, \tau_{xy_1}, \sigma_{x_2}, \sigma_{y_2}, \tau_{xy_2}, \sigma_{x_3}, \sigma_{y_3}, \tau_{xy_3}, \sigma_{x_4}, \sigma_{y_4},$

$\tau_{xy_4}, \sigma_{x_m}, \sigma_{y_m}, \tau_{xy_m}.$

where m - denotes the element centroid.

- B. Coordinates of the midpoints are computed by the subroutine.

1. Subroutine Name: ESCONT
2. Purpose:
Solves matrix equation $A * A \text{ transpose} * X = F$ for X .
3. Equations and Procedures:
The matrix equation $A * A \text{ transpose} X = F$ is solved for X by solving the matrix equations $A * XK = F$
 $A \text{ transpose} * X = XK$
 where A is a banded lower triangular matrix and X and F are column vectors.

 Procedure:
 (1) Rows ISTRT to ICALC of A are read from tape I7.
 (2) A call to KCALC routine computes XK .
 (3) A call to XCALK routine computes X .
 (4) Steps 1, 2 and 3 are repeated for each pass.
4. Input Arguments:

N	Order of system
NPASS	Number of computation passes necessary
NROW	Array for control of computation passes
IZR	Banding information array
NZEL	Banding information array
A	Storage array for input matrix
F	Storage array for input column
NTAPE	Input tape logical number
XK	Working storage array
NL	No. of load conditions
5. Output Arguments: X =Output answer column array
6. Error Returns: None
7. Calling Sequence:
CALL ESCONT (N, NPASS, NROW, IZR, NZEL, A, F, X, XK, NTAPE, NL)
8. Input Tapes:
Tape I7 contains input triangular matrix A . A is in banded form. Each row is a separate record.
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required: (2000 Bytes) 500 words

12. Subroutine User: BEQ SX

13. Subroutines Required:

KCALC

XCALK

- | | |
|-----------------------------|---|
| 1. Subroutine Name | FOMO |
| 2. Purpose | Process force cards |
| 3. Equations and Procedures | The cards are read from file L5 and counted by a counter KFORCE. The input values are (Force 1(i), i = 1, 2), F, and (F ₂ (i), i = 1, 2, 3); (Force 2(i) = F - F _n (i), i = 1, 2, 3). |
| 4. Input Arguments | <p>OUT = storage for reading data</p> <p>FORCE 1 = set id number, grid point number</p> <p>FN (i), i = 1, 2, 3 = components of force</p> <p>L5 = input file number</p> <p>L6 = output file number</p> <p>F = scale factor</p> |
| 5. Output Arguments | Force 2(i) for each component |
| 6. Error Returns | None |
| 7. Calling Sequence | Call FOMO (FORCE 1, FORCE 2, L5, NFO, K FORCE, OUT, L6) |
| 8. Subroutine User | ZZ |

1. Subroutine Name: GMPRD
2. Purpose:
Multiply two general matrices to form a resultant general matrix
3. Equations and Procedures:
The M by L matrix 'B' is premultiplied by the N by M matrix 'A' and the result is stored in the N by L matrix 'R'.
4. Input Arguments:
A Name of first input matrix
B Name of second input matrix
N Number of rows in A
M Number of columns in A and rows in B
L Number of columns in B
5. Output Arguments:
R Output matrix
6. Error Returns: None
7. Calling Sequence:
CALL GMPRD (A,B,R,N,M,L)
8. Input tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required: (656 Bytes) 164 words
12. Subroutine User: ELEM8
13. Subroutine Required: None
14. Remarks:
 1. All matrices must be stored as general matrices.
 2. Matrix R cannot be in same location as matrix A.
 3. Matrix R cannot be in same location as matrix B.
 4. Number of columns of matrix A must be equal to number of rows in matrix B.

1. Subroutine Name: GTPRD

2. Purpose:

Premultiply a general matrix by the transpose of another general matrix.

3. Equations and Procedures:

Matrix transpose of A is not actually calculated. Instead elements of matrix A are taken columnwise rather than row-wise for post-multiplication by matrix B.

4. Input Arguments:

A	Name of first input matrix
B	Name of second input matrix
N	Number of rows in A and B
M	Number of columns in A and rows in R
L	Number of columns in B and R

5. Output Arguments:

R	Name of output matrix
---	-----------------------

6. Error Returns: None

7. Calling Sequence:

CALL GTPRD (A,B,R,N,M,L)

8. Input Tapes: None

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (656 Bytes) 164 words

12. Subroutine User: ELEM8

13. Subroutine Required: None

14. Remarks:

1. Matrix R cannot be in the same location as matrix A.
2. Matrix R cannot be in the same location as matrix B.
3. All matrices must be stored as general matrices.

1. Subroutine Name: IGEN2
2. Purpose:
Compute eigenvalues used in buckling analysis.
3. Equations and Procedures:
Eberleins method is used. This consists of a sequence of similarity transporations which are intended to reduce the Euclidean norm of the matrix under study (A), so that it can practically speaking, be made arbitrarily normal.
4. Input Arguments:
A Matrix whose eigenvalues are desired
N Order of A-matrix
YR Used to control convergence (min. 1E-7 smallest element of A)
ISW=0 Do not form eigenvectors (control)
ID=6 Dimension of 'A' in calling routine
5. Output Arguments:
A Overlayed with matrix of eigenvalues along diagonal
IT Iteration counter (maximum of 50)
6. Error Returns:
IIT If off diagonal elements of 'diagonalized'
7. Calling Sequence:
CALL IGEN2 (N, YR, ISW, IT, IIT, ID, A, AA, T, TI, RES)
8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required: (5700 Bytes) 1425 words
12. Subroutine User: BUCKTB
13. Subroutine Required: None
14. Remarks: None

- | | |
|--------------------------------|---|
| 1. Subroutine Name | INSPC |
| 2. Purpose | Stores data obtained from input card
into working storage |
| 3. Equations and
Procedures | SPCINF = Out storage, SPCTYP |
| 4. Input Argument | SPCTYP = Special code for type of card
OUT = Storage for card data |
| 5. Output Argument | SPCINF
NSCARD = Counter for no. special input
cards |
| 6. Error Returns | |
| 7. Calling Sequence | Call INSPC (NSCARD, OUT, NSPCS, SPCTYP,
SPCINF) |
| 8. Subroutine User | |

- | | |
|-----------------------------|---|
| 1. Subroutine Name | INSRT1 |
| 2. Purpose | Stores element properties and material numbers into working storage |
| 3. Equations and Procedures | $\left. \begin{array}{l} F(I) = FA \\ G(I) = GA \\ MATNO(I) = NM \end{array} \right\} \begin{array}{l} \text{If } NA = NAST(I) \text{ and} \\ \text{If } NP = NPROP(I) \end{array}$ |
| 4. Input Argument | <p>FA = Element property</p> <p>GA = Element property</p> <p>NM = Material property SID</p> <p>NUM = Number elements</p> <p>NAST = Element id number</p> <p>NPROP = Property SID</p> <p>NA = Work value of NAST</p> <p>NP = Work value of NPROP</p> |
| 5. Output Argument | |
| 6. Error Return | None |
| 7. Calling Sequence | Call INSRTI (NAST, NA, NPROP, NP MATNO, NM, F, FA, G, GA, NUM) |
| 8. Subroutine User | |

1. Subroutine Name: KCALC

2. Purpose:

Solve for XK where $A \cdot XK = F$ and A is a banded lower triangular matrix.

3. Equations and Procedures:

Determine elements ISTRT to ICALC of each load vector XK in the matrix equation $A \cdot XK = F$.

$$XK(1) = \frac{F_1}{A_{11}} \quad XK(I) = F(I) - \sum_{L=1}^{I-1} A_{LI} XK(L) \quad I > 1$$

This constitutes the first step in equation solution by Cholesky or "square root" method.
Repeat above procedure for all load conditions.

4. Input Arguments:

ISTRT	Beginning row number of computation pass
ICALC	End row number of computation pass
IZR	Number zero elements in row of reduced matrix
NZEL	Cumulative total of nonzero elements in rows 1 through i - 1 of reduced matrix
A	Storage array for input matrix
F	Column vector array
N	Order of System
NL	Number of load conditions

5. Output Arguments: XK = output vector array

6. Error Returns: None

7. Calling Sequence:

CALL KCALC (ISTRT, ICALC, IZR, NZEL, A, F, XK, N, NL)

8. Input Tapes: None

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (810 Bytes) 203 words

12. Subroutine User: ESCONT

13. Subroutines Required: None

- | | |
|-----------------------------|--|
| 1. Subroutine Name | KMAT |
| 2. Purpose | Generate stiffness matrix for membrane triangle |
| 3. Equations and Procedures | $SYMM = BINV^* C BINV * H * AREA$ |
| 4. Input Argument | <p>S = Intermediate work storage</p> <p>BIUV = BINV matrix (transformation)</p> <p>C = Elaso C matrix</p> <p>AREA = Area of triangle</p> <p>H = Thickness of plate</p> |
| 5. Output Arguments | KSymm = output symmetric stiffness matrix |
| 6. Error Returns | None |
| 7. Calling Sequence | CALL KMAT (S, BINV, C, KSymm, AREA, H) |
| 8. Subroutine User | ORTHO3 |

1. Subroutine Name: MFGR

2. Purpose:

Determine rank and linearly independent rows and columns of a given matrix

3. Equations and Procedures:

The standard Gaussian elimination technique with complete pivoting is used. This implies that the rows and columns of the given M by N matrix A are interchanged at each elimination step if necessary. The interchange information is recorded in two integer permutation vectors IROW and ICOL.

The I^{th} $\left\{ \begin{array}{l} \text{Row} \\ \text{Column} \end{array} \right\}$ of the interchanged matrix corresponds

to the $\left\{ \begin{array}{ll} \text{IROW}(I)^{\text{th}} & \text{Row} \\ \text{ICOL}(I)^{\text{th}} & \text{Column} \end{array} \right\}$ in the original matrix A

Initially $\text{IROW}(J) = J$ and $\text{ICOL}(J) = J$

4. Input Arguments:

A	Given matrix with M rows and N columns
M	Number of rows of matrix A
N	Number of cols of matrix A
EPS	Test value for zero affected by roundoff noise

5. Output Arguments:

IRANK	Resultant rank of given matrix
IROW	Integer vector of dimension M containing the subscripts of basic rows in $\text{IROW}(1) \dots \text{IROW}(\text{RANK})$
ICOL	Integer vector of dimension N containing the subscripts of basic columns in $\text{ICOL}(1) \text{ UP TO } \text{ICOL}(\text{RANK})$

6. Error Returns: None

7. Calling Sequence:

CALL MFGR (A,M,N,EPS,IRANK,IROW,ICOL)

8. Input Tapes: None

9. Output Tapes: None

10. Scratch Tapes: None

- 11. Storage Required:
(2092 Bytes) 523 words
- 12. Subroutine User: ELEM8
- 13. Subroutine Required: None
- 14. Remarks: None

1. Subroutine Name: MINV
2. Purpose: Invert a matrix
3. Equations and Procedures:
Uses the standard Gauss-Jordan method in which the inverted matrix is stored back on itself.
4. Input Arguments:
A Matrix to be inverted
N Order of matrix
D Determinant value
L Work vector of length N
M Work vector of length N
5. Output Arguments:
A Contains the inverted matrix
6. Error Returns:
If $D=0$, matrix is singular
7. Calling Sequence:
CALL MINV (A,N,D,L,M)
8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required: (2068 Bytes) 517 words
12. Subroutine User:
ELEM4, ELEM7, ELEM8
13. Subroutine Required: None
14. Remarks: None

1. Subroutine Name: MODIFY

2. Purpose:

Evaluate the recursion relationships for the iterative determination of an elements design variable when a displacement constraint is violated.

3. Equations and Procedures:

The general recursion relationship is

$$A_j^{n+1} = \frac{A_j^n}{(\Delta^* - \Delta_0)} \left(\frac{\sum_k \frac{|\delta^P|^T [K_{EL}] |\delta^Q|}{C_{kj}}}{\sum_k C_{kj} L_{kj} \rho_{kj}} \right)^{\frac{1}{2}} \times \sum_i A_i \left(\frac{\sum_l C_{li} L_{li} \rho_{li} \sum_1 \frac{|\delta^P|^T [K_{EL}] |\delta^Q|}{C_{li}}}{C_{li}} \right)^{\frac{1}{2}}$$

which allows for all members of a linked group to participate in the redesign. Members are considered passive in the above equation if the size of that member is defined by other than a displacement constraint. The largest area generated in the above equation is taken from the combined set resulting from all loads and displacement constraints. These areas are then compared with those based upon stresses or minimum sizes and the larger values selected for each member.

4. Input Arguments:

SIGL, SIGU Lower and upper stress bounds for each element
ALL Minimum design variable
DISPU, DISPL Upper and lower limits for displacement constraints
DELTA Displacement matrix
BIGS Residual strength ratio output by scale routine
LIST Array containing number of stress components for each element
PAR Element information array originally on NSS3

5. Output Arguments:

AREA New design variable for each element

6. Error Returns: None

7. Calling Sequence:

CALL MODIFY (SIGL,SIGU,ALL,N7,DISPU,DISPL,NBDF,NE,
DELTA,BIGS,AREA,STRESS,LLST,PAR,NBDF2,NE2,AQEA,N5,
N6,X,AREAD,NSTRES,NSS1)

8. Input Tapes:

NSS1 (Unit 1) Element stiffness matrices

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (7516 Bytes) 1879 words

12. Subroutine User: ATWO

13. Subroutine Required: None

14. Remarks: None

1. Subroutine Name: NEWS

2. Purpose:

To determine max core available vs problem size and set up dynamic storage subscripts for the initialization phase of the program.

3. Equations and Procedures:

Storage requirements for the arrays used by the AONE (utilization routine) are computed from the input parameters.

If the storage required exceeds MAXCOR (the size of the W array) then IER is set to one, a message is written describing the additional storage required and the routine returns to the main routine.

If the storage available is adequate, locations in the W array are computed for the required arrays and routine AONE is called.

4. Calling Arguments: (* Input)

*N1	Control for degrees of freedom of a node set to 3 internally.
*N2	No. of nodes in problem.
*ITOT	Number of elements in problem
*NSG	Number of components in integer array indicating linked groups
*NAAALL	Number of generalized constraint groups (NAA) + cumulative length of all groups
*NBCU	Total number of constrained degrees of freedom for a symmetric load condition
*NSYM	Number of symmetric load conditions
*NONSYM	Number of nonsymmetric load conditions
*NASYM	Number of anti-symmetric load conditions
*NDL	Number of individual constraints
*NAA	Number of generalized constraints
*NTAPE	Input tape for AONE routine (Unit 8)
*NPOT	Print-out data set (Unit 6)
*NSS1)	Unit 1
*NSS2)	Unit 2
*NSS3)	Unit 3
*NSS4)	Unit 4
*IBUCL	Buckling control
*NNZL	Number of loads input
*NALD	Total number of load conditions (NSYM+NASYM+NONSYM)
*KLN2	Number of nodes on symmetry plane
*ITERN	Maximum number of iterations
*NTODS	Number of title cards
*IREST	Print control for printing input
IELI	Integer array indicating number of each type element, e.g., IELI(5)=N type 5 elements

NREACT	Integer array six elements long indicating total number of constraints e.g. NREACT(1)= number of constrained U components
*C1INP	Convergence control
*C2INP	Convergence control
NRDF	Number of reduced degrees of freedom for symmetric load condition
NRDF2	Number of reduced degrees of freedom for antisymmetric load condition
NEAA	Number of generalized constraint groups (NAA) + cumulative length of all groups
NEA2	Same as above
NDLI	Sum of individual constraints minus bounded constraints for symmetric load condition
NDL2	Same as above except for antisymmetric load condition
NBOUN2	Total number of constrained degrees of freedom for antisymmetric load condition
*KNLMAX	Max. length of a generalized constraint group
*IRST	Calculation control which determines use of OPDVIR section
*MAXCOR	Size of 'W' array available for dynamic storage
*W	Array used for dynamic storage
IER	Error control

5. Error Returns:

IER \neq 0 not enough core available to complete initialization

6. Calling Sequence:

CALL NEWS(N1,N2,ITOT, NSG,NAAALL, NBOU,NSYM,NONSYM,NASYM
NDL,NAA,NTAPE,NPOT,NSS1,NSS2,NSS3,NSS4,IBUKL,NNZL,NAID,
KLN2,ITERN,NTODS,IREST,IELI,NREACT,C1INP,C2INP,NRDF,NRDF2,
NEAA,NEA2,NDL1,NDL2,NBOUN2,KNLMAX,IRST,IBGP,MAXCOR,W,IER)

7. Input Tapes: None

8. Output Tapes: None

9. Scratch Tapes: None

10. Storage Required: (3436 Bytes) 859 words

11. Subroutine User: MAIN

12. Subroutine Required: AONE

13. Remarks: None

1. Subroutine Name: OPINPT

2. Purpose:

To complete NTAPE (Unit 8); input to the AONE routine.

3. Equations and Procedures:

Process input needed by the AONE routine in this order.

COORD
ELEM
OEXTERN
LINKS
BOUND
OLOADS
ICON
GCON
OPDVIR

Place all information on NTAPE (Unit 8).
Print diagnostic messages if necessary.

4. Input Arguments:

NPIT	Unit 5 (card reader)
NPOT	Unit 6 (printer)
NTAPE	Unit 8 (tape)
N2	Number of nodes
NDL	Number of individual constraints
NAA	Number of generalized constraints
NNZL	Number of input cards for loads
NSS1	Unit 1 (tape)
NREF	Info from System section input
NGRD	
NDOFPN	
NALD	
ITOT	
NIBCP	

5. Output Arguments:

NREACT	Array indicating number of bounded DOF
IER	Error indicator

6. Error Returns: IER=0

7. Calling Sequence:

CALL OPINPT(NPIT, NPOT, NTAPE, NREF, NGRD, NDOFPN, NALD, ITOT,
NIBCP, N1, N2, NSGIN, NDL, NAA, NDLA, NREACT, NNZL, IELI, IRST,
NAANUM, NSG, NSS1, KNLMAX, IER, GRID, IBOUND, NBOUND, INODE,
NBDF, DISPU, DISPL, LINKB, LINKN, ILINK, DVIR, IBUCKL, NAM, IBO,
IG1, IG2, IG3, IBGP)

- 8. Input Tapes: None
- 9. Output Tapes: NTAPE
- 10. Scratch Tapes:
NSSL (Unit 1) used to merge ELEM and OEXTRN sections
- 11. Storage Required: (15844 Bytes) 3961 words
- 12. Subroutine User: MAIN
- 13. Subroutine Required: None
- 14. Remarks: None

1. Subroutine Name OPTIM2
2. Purpose:
 To control the program execution.
3. Equations and Procedures:
 Identify all external files and rewind them.
 Read REPORT, TITLE, SYSTEM and OPTIM sections to define
 variables needed for dynamic storage.
 If there are any title cards read them and put them on
 NTAPE (Unit 8).
 Print message if any sections are out of order.
 Call OPINPT routine to read rest of input sections.
 If there is any error (IER#0) call exit.
 Call NEWS routine to perform dynamic storage allocation
 and call routines to perform initialization.
 If there is any error (IER#0) call exit.
 Call SIZE routine to perform dynamic storage allocation
 and call routines to perform problem calculation.
 If there is any error (IER#0) call exit.
4. Input Arguments: None
5. Output Arguments: None
6. Error Returns: (IER#0) call exit
7. Calling Sequence: Call OPTIM2 (WORK, NPIT)
8. Input Tapes: WORK = Work storage
 NPIT = Input file number
9. Output Tapes: NTAPE (Unit 8)
10. Scratch Tapes:
 NSS1 (Unit 1)
 NSS2 (Unit 2) These tapes are defined and rewound
 NSS3 (Unit 3) only.
 NSS4 (Unit 4)
11. Storage Required:
 (35630 Bytes) 8907 words
 This size includes 'W' work array of 8000.
 This array is used to dynamically locate arrays.
12. Subroutine User: Not applicable
13. Subroutine Required: OPINPT
 NEWS
 SIZE
14. Remarks: None

1. Subroutine Name: PS3D

2. Purpose:

Create cubic equation coefficients from stress components for beam (tube) element

3. Equations and Procedures:

$$\tau^3 - (\tau_{xx} + \tau_{yy} + \tau_{zz})\tau^2 + (\tau_{xx}\tau_{yy} + \tau_{yy}\tau_{zz} + \tau_{zz}\tau_{xx}$$

$$- \tau_{xz}^2 - \tau_{xy}^2 - \tau_{yz}^2)\tau - (\tau_{xx}\tau_{yy}\tau_{zz} - \tau_{xx}\tau_{yz}^2 - \tau_{yy}\tau_{xz}^2$$

$$- \tau_{zz}\tau_{xy}^2 + 2\tau_{xy}\tau_{yz}\tau_{xz}) = 0$$

or

$$\tau^3 - A\tau^2 + B\tau - C = 0$$

4. Input Arguments:

S1 - S6. Stress components (xx,yy,zz,xy,yz,zx)
XX Proportioning factor

5. Output Arguments:

A }
B } Roots returned from cubic
C }

6. Error Returns: None

7. Calling Sequence:

CALL PS3D(S1,S2,S3,S4,S5,S6,XX,A,B,C,)

8. Input Tapes: None

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (696 Bytes) 176 words

12. Subroutine User: PS3R

13. Subroutine Required: CUBIC

14. Remarks: None

1. Subroutine Name: PS3R
2. Purpose: Normalize Stresses
3. Equations and Procedures:
 $X = 1/\text{average stress}$
Multiply all stresses by average stress
4. Input Arguments: B1 \rightarrow B6
5. Output Arguments:
A, B, C Principal stresses of Beam (tube) element
6. Error Returns: None
7. Calling Sequence:
CALL PS3R (B1, B2, B3, B4, B5, B6, A, B, C)
8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required: (664 Bytes) 166 words
12. Subroutine User: SCALE
13. Subroutine Required: PS3D
14. Remarks: None

1. Subroutine Name	READI
2. Purpose	Reads and modifies input data
3. Equations and Procedures	Reads the card data from file J5, right adjust the data fields, counts each data type, prints the data and finally stores the modified data on file J6
4. Input Argument	LABEL = array of BCD label codes ILAB = array of label integers ISPECL = array of special labels NILAB = total no. of labels J6 = output file number NSPECL = total no. special labels
5. Output Arguments	NCARDS = array of card counters L7CASE = code to indicate that file is = 7
6. Error Returns	None
7. Calling Sequence	CALL READI (LABEL, ILAB, ISPECL, NCARDS, NILAB, NSPECL, J6, L7CASE)
8. Subroutine User	SORT
9. Subroutines Used	ADJUST

1. Subroutine Name: SCALE

2. Purpose:

To scale the stresses, displacements and design variables of the structure. For the in-core solution

3. Equations and Procedures:

- A. Determine maximum ratio BIG = actual stress/allowable for all elements and all load conditions.
For the beam (tube) element use maximum principle stress from both ends as allowable.
For all other elements use Von Mises reference stress

$$\sigma_{REF} = (\sigma_x^2 - \sigma_y^2 - \sigma_x \sigma_y + 3\tau_{xy}^2)^{\frac{1}{2}}$$

- B. Determine max. ratio (BIG) using individual and generalized displacement constraints

- C. Scale element design variables (use minimum if larger).
If buckling is specified use this criteria for quadrilateral selected.

- D. Scale all actual element stresses

$$\hat{\sigma} = \hat{\sigma}_{act}/BIG$$

- E. Determine residual ratio (BIGS) for each element after scaling stresses. First use

$$BIGS(I) = \frac{\text{minimum design var.}}{\text{actual design var.}}$$

Then compare against ratio obtained as in step B).
Use maximum for each element.

4. Input Arguments:

LK	No. of stresses
SIGL	Lower stress limit for each element
SIGU	Upper stress limit for each element
ALL	Minimum design variable for each element
N7	Not used
DISPU	Upper displacement limits
DISPL	Lower displacement limits reduced deg. of free.
NBDF	Integer array locating RDOF of individual constraints symmetric load conditions
NE	Integer array locating RDOF of generalized constraints anti-symmetric load conditions
DELTA	Displacement matrix

BIGS	Residual ratio for each element after scaling
STRESS	Stress matrix
LIST	Integer array giving no. of stress components for each element
PAR	Array containing element weight factors and the parameter x_2/x_3 for element 4 (quadrilateral)
NBDF2	Integer array locating RDOF of individual constraints for anti-symmetric load conditions
NE2	Same as NE except for anti-symmetric load condition
AREA	Not used
AL }	Lengths of sides of quadrilaterals
BL }	
IBUKL }	Constant Array - used to control buckling analysis
IBK }	

5. Output Arguments:

AQEA Element design parameters

6. Error Returns: None

7. Calling Sequence:

CALL SCALE (LK, SIGL, SIGU, ALL, N7, DISPU, DISPL, NBDF, NE, DELTA, BIGS, AREA, STRESS, LIST, PAR, NBDF2, NE2, AQEA, AL, BL, IBUKL, IBK)

8. Input Tapes: None

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (9110 Bytes) 2277 words

12. Subroutine User: ATWO

13. Subroutine Required:

PS3R
BUCKTB

1. Subroutine Name: SCALE1

2. Purpose:

To scale the stresses, displacements and design variables of the structure for an "out-of-core-solution".

3. Procedure:

The procedure followed here is identical to the SCALE routine except the stress matrix is on data set NSS3 (one column/record).

A. Determine max. ratio (BIG)= actual stresses/allowable stress for all elements and all load conditions.
For the beam (tube) element use matrix principle stress from both ends as allowable
For all other elements use Von Misses Reference stress.

B. Determine max. ratio (BIG) using individual and generalized displacement constraints.

C. Scale element design variables (use specified minimum (if larger).
If buckling is specified use this criteria for quadrilaterals selected.

D. Scale all actual element stresses.

$$\bar{S} = S_{act}/BIG$$

E. Determine residual ratio (BIGS) for each element after scaling stresses

4. Input Arguments:

See SCALE write-up for more complete listing of Arguments.

LK	No. of stresses
SIGL	Lower stress limit for each element
SIGU	Upper stress limit for each element
ALL	Minimum design variable for each element
DISPU	Upper displacements limits
DISPL	Lower displacement limits
DELTA	Displacement matrix
NSS3	Data set containing stress matrix

5. Output Arguments:

AREA Element design parameters

6. Error Returns: None

7. Calling Sequence:

CALL SCALE1 (LK,SIGL,SIGU,ALL, N7,DISPU,DISPL,NBDF,NE,
DELTA,BIGS,AREA,STRESS,LIST,PAR,NBDF2,NE2,AQEA,AL,BL,
IBUKL,IBK,NSS3,BIG)

8. Input Tapes:

NSS3 Stress matrix (1 column/record)

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (8836 Bytes) 2209 words

12. Subroutine User: ATW01

13. Subroutine Required:

PS3R
BUCKTB

1. Subroutine Name: SIZE

2. Purpose:

To determine max. core available vs problem size and set up dynamic storage subscripts for the calculation phase of the program in-core solution.

3. Equations and Procedures:

Storage requirements for the arrays used by the ATWO (calculation routine) are computed from the input parameters.

If the storage required exceeds MAXCOR (the size of the W array) then a message is written describing the additional storage required and the program calls the SIZE1 routine for an attempt at an out-of-core solution.

If the storage available is adequate, locations in the 'W' array are computed for the required arrays and routine ATWO is called.

4. Input Arguments:

NELEM	Total number of elements
NRDF	No. of reduced degrees of freedom for symmetric load conditions
NSYM	No. of symmetric load conditions
NASYM	No. of antisymmetric load conditions
NCNSYM	No. of nonsymmetric load conditions
NPOT	Printer data set
NSS1-NSS5	Data sets
IP1, IP2	Print controls
IPRINT	
MAXCOR	Size of 'W' array
W-WORK	Array for dynamic storage

5. Output Arguments:

IER=0 indicates error (problem exceeds storage reserved)

6. Error Returns:

If MAXCOR is exceeded then the ATWO routine is not called and the program writes storage required. Then a call is made to the SIZE1 routine.

7. Calling Sequence:

CALL SIZE (NELEM, NRDF, NDL1, NAA, NRDF2, NDL2, NSYM, NASYM, NCNSYM, IEL1, NSG, NEAA, NEA2, NDL, NBOU, NBOUN2, NPOT, NSS1, NSS2, NSS3, NSS4, NSS5, IP1, IP2, IRST, ITERN, IPRINT, IBUKL, MAXCOR, W, IER)

8. Input Tapes: None
9. Output Tapes: None
10. Scratch Tapes: None
11. Storage Required: (2780 Bytes) 695 words
12. Subroutine User: MAIN
13. Subroutine Required:
- A TWO
SIZEL
14. Remarks: None

1. Subroutine Name: SIZE1

2. Purpose:

To determine max. core available vs problem size and set up dynamic storage subscripts for the calculation phase of the program out-of-core solution.

3. Equations and Procedures:

Storage requirements for the arrays used by the ATW01 (out-of-core) calculation routine are computed from the input parameters.

If the storage required exceeds MAXCOR (the size of the W array) then a message is written describing the additional storage required and the program halts after a return to the MAIN routine.

If the storage available is adequate, locations in the 'W' array are computed for the required arrays and routine ATW01 is called.

4. Input Arguments:

NELEM	Total number of elements
NRDF	No. of reduced degrees of freedom for symmetric load conditions
NSYM	No. of symmetric load conditions
NASYM	No. of antisymmetric load conditions
NONSYM	No. of nonsymmetric load conditions
NPOT	Printer data set
NSS1-NSS5	Data sets
IP1, IP2, } IPRINT }	Print controls
MAXCOR	Size of 'W' array
W	Work array for dynamic storage

5. Output Arguments:

IER=0 indicates error (problem exceeds storage reserved)

6. Error Returns:

If MAXCOR is exceeded then the ATW0 routine is not called and the program writes storage required. A return to the 'MAIN' routine then halts the program.

7. Calling Sequence:

CALL SIZE1 (NELEM, NRDF, NDL1, NAA, NRDF2, NDL2, NSYM, NASYM, NONSYM, IEL1, NSG, NEAA, NEA2, NDL, NBOU, NBOUN2, NPOT, NSS1, NSS2, NSS3, NSS4, NSS5, IP1, IP2, IRST, ITERN, IPRINT, IBUKL, MAXCOR, W, IER)

8. Input Tapes: None

- 9. Output Tapes: None
- 10. Scratch Tapes: None
- 11. Storage Required: (2728 Bytes) 682 words
- 12. Subroutine User: SIZE
- 13. Subroutine Required: ATW01

- | | |
|--------------------------------|---|
| 1. Subroutine Name | SMAT |
| 2. Purpose | Generate stress element matrix for
membrane triangular plate with ortotropic
properties |
| 3. Equations and
Procedures | $SMAK = T * C * BINV$ where T is generated in
SMAT, C and BINV are input |
| 4. Input Arguments | C = 6 x 6 matrix
BINV = 6 x 6 matrix |
| 5. Output Arguments | SMAK = 3 x 6 stress matrix |
| 6. Error Returns | None |
| 7. Calling Sequence | CALL SMAT (C, SMAK, BINV) |
| 8. Subroutine User | ORTHO3 |

1. Subroutine NAME	Sort
2. Purpose	Sort and count data based on LABEL information.
3. Equations and Procedures	Using READI, the data is read and counted. The final counters are then modified.
4. Input Arguments	L4 = file number for storage of sorted input deck
5. Output Arguments	<div> <div>{</div> <div> MEL = total no. elements MGR = total no. grid points MMT = " " materials MOGCON = " " generalized constraints MICON8 = " " INdividual Constraints MILINKS = " " Links MFO = " " Forces MMO = " " Moments MLOADS = " " Loads </div> </div>
6. Error Returns	None
7. Calling Sequence	Call Sort (MEL, MGR, MMT, MOGCON, MICON8, MILINKS, MFO, MMO, MLOADS, MGROUF, MSPCS, L4, L7CASE)
8. Subroutine User	Main Program
9. Subroutines Used	READ I

1. Subroutine NAME	SPCSUB
2. Purpose	Process SPC (single point constraint) Cards
3. Equations and Procedures	Boundary information is processed as read in OUT (I) and NOUT (I). This information is interpreted and stored in LBOUND.
4. Input Arguments	NOUT = input data storage OUT = input data storage NSPC = no. SPC cards KWORD = work storage NUM = work storage NKIND = type of boundary information available NGR = total no. grid points
5. Output Arguments	LBOUND = boundary array information NBCARD = counter of boundary information
6. Error Returns	None
7. Calling Sequence	Call SPCSUB (NOUT, OUT, NSPC, KWORD, NUM, LBOUND, NBCARD, NKIND, NGR)
8. Subroutine User	ZZ
9. Subroutines Used	XTRAK

1. Subroutine Name: TCONTX
2. Purpose:
This routine controls tape flow for the triangularization routine.
3. Equations and Procedures:
 1. Controls for setting up computation passes are computed in ICALC and ISTRT.
 2. A portion of the input matrix A is read in from Tape I3=MTAPE.
 3. This information is given to the routine TTRI which actually performs the triangularization for row numbers ISTRT to ICALC.
 4. This triangularized output portion in A is stored on tape NTAPE = I7.
 5. Computation is repeated for each portion of the matrix until all rows are completed.
4. Input Arguments:

N	order of system to be handled
IZR	banding information array
NZEL	banding information array
A	storage array for input row of banded matrix which is read by routine
NTOTAL	total number of words which can be considered as a "full-core"
ATRI	intermediate storage array equals length of maximum order
MTAPE	input tape logical number
NTAPE	output tape logical number
5. Output Arguments:

IERROR	error indication value
WS	accumulative determinant
6. Error Returns:
IERROR not = 0 if WS is returned from TTRI as less than zero
7. Calling Sequence:
CALL TCONTX (N, IZR, NZEL, A, NTOTAL, ATRI, MTAPE, NTAPE, IERROR, WS)

8. Input Tapes:

MTAPE = I3 = input matrix A in banded row form.
Each row equals 1 record.

9. Output Tapes:

NTAPE = I7 = triangularized matrix T in banded row
form. Each row equals 1 record.

10. Scratch Tapes: None

11. Storage Required: (1592 Bytes) 398 words

12. Subroutine User: ATW01

13. Subroutines Required: TTRI

- | | |
|-----------------------------|---|
| 1. Subroutine NAME | TMAT |
| 2. Purpose | Generate transformation matrix for triangular plate orthotropic material angle. |
| 3. Equations and Procedures | $T = \begin{bmatrix} \cos^2 \theta & \sin^2 \theta & \sin \theta \cos \theta \\ \sin^2 \theta & \cos^2 \theta & -\sin \theta \cos \theta \\ -2 \sin \theta \cos \theta & 2 \sin \theta \cos \theta & \cos^2 \theta - \sin^2 \theta \end{bmatrix}$ |
| 4. Input Arguments | THETA = material angle |
| 5. Output Arguments | T = 3 x 3 matrix |
| 6. Error Returns | None |
| 7. Calling Sequence | CALL TMAT (THETA, T) |
| 8. Subroutine User | ORTHO3 |
| 9. Subroutines Used | None |

1. Subroutine Name: TTTRI

2. Purpose:

To triangularize rows ISTRT to ICALC of a banded matrix A.

3. Equations and Procedures:

1. This routine triangularizes rows ISTRT to ICALC of a banded matrix A where rows 1 to ISTRT-1 of the A matrix (already triangularized) are on tape NTAPE.

2. If ISTRT = 1, then NTAPE and work storage ATRI are not used since A is assumed to be in core.

3. Procedure:

Using Cholesky technique, the off diagonal terms of the portion in core are triangularized. Off diagonals are then computed. Output is stored in array A.

4. Cholesky equations:

$$(1) \quad s_{11} = (a_{11})^{\frac{1}{2}} \quad (3) \quad s_{1i} = (a_{1i} - \sum_{q=1}^{i-1} s_{1q}^2)^{\frac{1}{2}} \quad i > 1$$

$$(2) \quad s_{ij} = \frac{a_{ij}}{s_{11}} \quad (4) \quad s_{ij} = \frac{a_{ij} - \sum_{q=1}^{i-1} s_{1q} s_{qj}}{s_{11}} \quad j > i$$

4. Input Arguments:

ISTRT	Beginning row of triangularized portion
ICALC	End row of triangularized portion
IZR	Banding information array
NZEL	Banding information array
NTAPE	logical tape number of input tape. NTAPE=I7
A	Storage array for input A and also output array
ATRI	Working storage array

5. Output Arguments: A=output array

6. Error Returns:

IERROR = I = row numbers such that $WS = s_{11}$ is not greater than zero.

7. Calling Sequence:

CALL TTRI (ISTRT,ICALC,IZR,NZEL,NTAPE,A,ATRI,IERROR,WS)

8. Input Tapes:

NTAPE = tape which contains already triangularized rows of matrix.

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (1844 Bytes) 461 words

12. Subroutine User: TCONTX

13. Subroutines Required: None

1. Subroutine NAME	WRITEL
2. Purpose	Tests character of element connection card and writes element information into file.
3. Equations and Procedures	If C_1 and C_3 are 0, C_2 and C_4 are stored. If C_2 & C_4 are 0, C_1 & C_3 are stored.
4. Input Arguments	$L7$ = Output file number IGR = Grid point number M = Position of A array to be restored C_1, C_2, C_3, C_4 = Input codes
5. Output Arguments	IGR and A array are stored on file $L7$
6. Error Returns	None
7. Calling Sequence	CALL WRITEL ($C_1, C_2, C_3, C_4, M, IGR, L$)
8. Subroutine User	ZZ
9. Subroutines Used	None

1. Subroutine Name: XCALK

2. Purpose:

Solves for X where $A \cdot X = XK$ and A is upper triangular matrix.

3. Equations and Procedures:

Determine ISTRT to ICALC of each load vector X in the matrix equation $A \cdot X = XK$ where A is upper triangular matrix and X and XK are column vectors.

$$X(N) = \frac{XK(N)}{A_{nn}} \quad X(I) = XK(I) - \sum_{L=I+1}^N A_{IL} X_L \quad I < N$$

This constitutes the second part in calculating an equation solution by Cholesky or "square root" method. Repeat above procedure for all load conditions.

4. Input Arguments:

N	Order of system
ISTRT	Beginning row number of computation pass
ICALC	End row number of computation pass
IZR	Number zero elements in row of reduced matrix.
NZEL	Cumulative total of nonzero elements from row 1 through 1 - i of reduced matrix
A	Storage array for matrix
XK	Column vector array
NL	No. of load conditions

5. Output Arguments:

X	Output vector array
---	---------------------

6. Error Returns: None

7. Calling Sequence:

CALL XCALK (N, ISTRT, ICALC, IZR, NZEL, A, XK, X, NL)

8. Input Tapes: None

9. Output Tapes: None

10. Scratch Tapes: None

11. Storage Required: (1116 Bytes) 279 words

12. Subroutine User: ESCONT

13. Subroutines Required: None

- | | |
|-----------------------------|--|
| 1. Subroutine NAME | XTRAK |
| 2. Purpose | Interpret degree of freedom information |
| 3. Equations and Procedures | Interprets NWORD and breaks this down into 6 individual components. These components are then stored in KWORD array. |
| 4. Input Arguments | NWORD = No. components input word
NP = Control word |
| 5. Output Arguments | KWORD = Output data array
NUM = Total no. DOF recognized |
| 6. Error Returns | None |
| 7. Calling Sequence | CALL XTRAK (NWORD, KWORD, NUM, NP) |
| 8. Subroutine User | SPCSUB |
| 9. Subroutines Used | None |

- | | |
|--------------------------------|---|
| 1. Subroutine NAME | XTRAK 2 |
| 2. Purpose | Interpret degree of freedom
information for generalized constraint
data. |
| 3. Equations and
Procedures | Checks on information supplied in
NP and stores codes into LGCON array. |
| 4. Input Arguments | NP = Input word to be interpreted
NM = 2nd input word to be interpreted.
NODE = Node point number |
| 5. Output Arguments | LGCON = Generalized constraint array |
| 6. Error Returns | None |
| 7. Calling Sequence | CALL XTRAK 2 (LGCON, NODE, NP, NM) |
| 8. Subroutine User | |
| 9. Subroutines Used | XTRAK |

1. Subroutine NAME	ZZ
2. Purpose	Generates OPTIM data which is input by NASTRAN format input cards.
3. Equations and Procedures	Each card is read and interpreted based on content and use in the OPTIM program.
4. Input Arguments	L5 = Input file tape number L7 = Output file tape number
5. Output Arguments	All of the grid point, boundary condition, element, material property, load, constraint and buckling information arrays needed by OPTIM.
6. Error Returns	
7. Calling Sequence	CALL ZZ (NAST, NOPT, MATNO, NPROP, NBUCK, NNODES, NOID, REF, OPDVIR, LBOUND, COOR, AMAT, MID, EYEC, LINKS, NEL, NGR, NMT, NICON8, NLINKS, NOGCON, NP, PA, NAP, GA, NFO, NMC, NLOADS, NSPCS, IGRID, SPCINF, GCOND, FORCE3, ANGLE, FORCE1, FORCE2, MOMNT1, MOMNT2, OPLOAD, GROUP, L5, L7).
8. Subroutine User	Main program
9. Subroutines Used	None

SECTION 5

PROBLEM SIZE LIMITATIONS

The key limitations are brought about by the total number of elements, number of load conditions and the number of degrees of freedom in the problem.

Due to dynamic storage allocation techniques the problem size can be controlled by changing two cards in the 'MAIN' routine. Both the dimension of the 'WORK' array (card MAIN0050) and the size of the variable 'NWORK' (card MAIN 0290) must be equal. The delivered size is 20,000 words, but may be adjusted to your system.

If there is insufficient storage space defined for a problem the program will print a message indicating the amount of storage required for the problem and the amount of storage reserved by the above mentioned cards in the 'MAIN' routine. To execute the problem modify the dimension and 'NWORK' variable to be what the problem needs or reduce the number of elements, number of load conditions and/or number of degrees of freedom indicated on the input sheet.

SECTION 6

STORAGE ALLOCATIONS

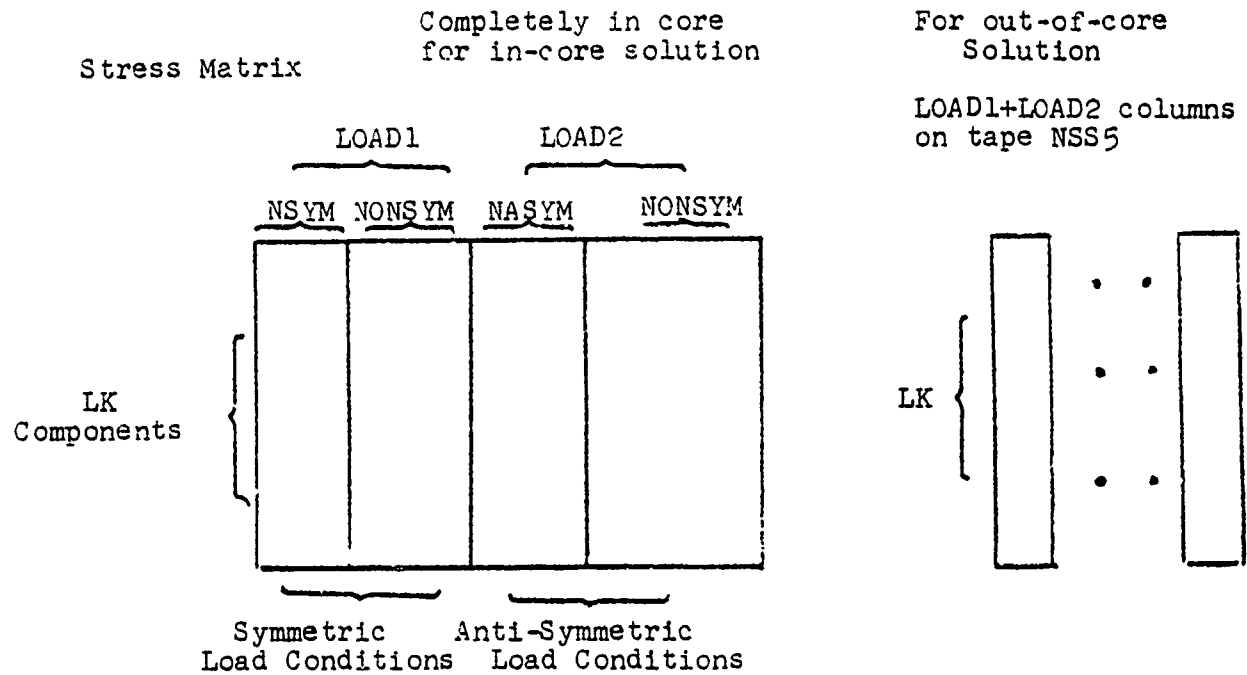
This section includes two diagrams indicating the manner of arranging the stress and displacement matrices to handle all load conditions.

The key to handling non-symmetric loads and displacements is in defining the nonsymmetric load as a symmetric and an anti-symmetric load.

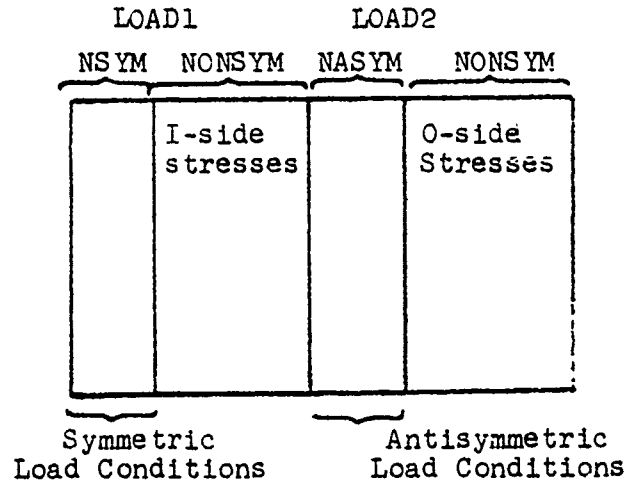
The definition of a number of key parameters used in the diagrams follows:

- NDL1 - Total no. of individual constraints minus any constraints that may be bounded during execution of the problem. For symmetric load conditions.
- NDL2 - Same as above except for anti-symmetric load conditions.
- NAA - No. of generalized constraints, all are assumed unbounded.
- NRDF - No. of reduced degrees of freedom (i.e., all bounded degrees of freedom removed) for symmetric load condition.
- NRDF2 - Same as above except for anti-symmetric load condition.

See Figures 4 and 5.



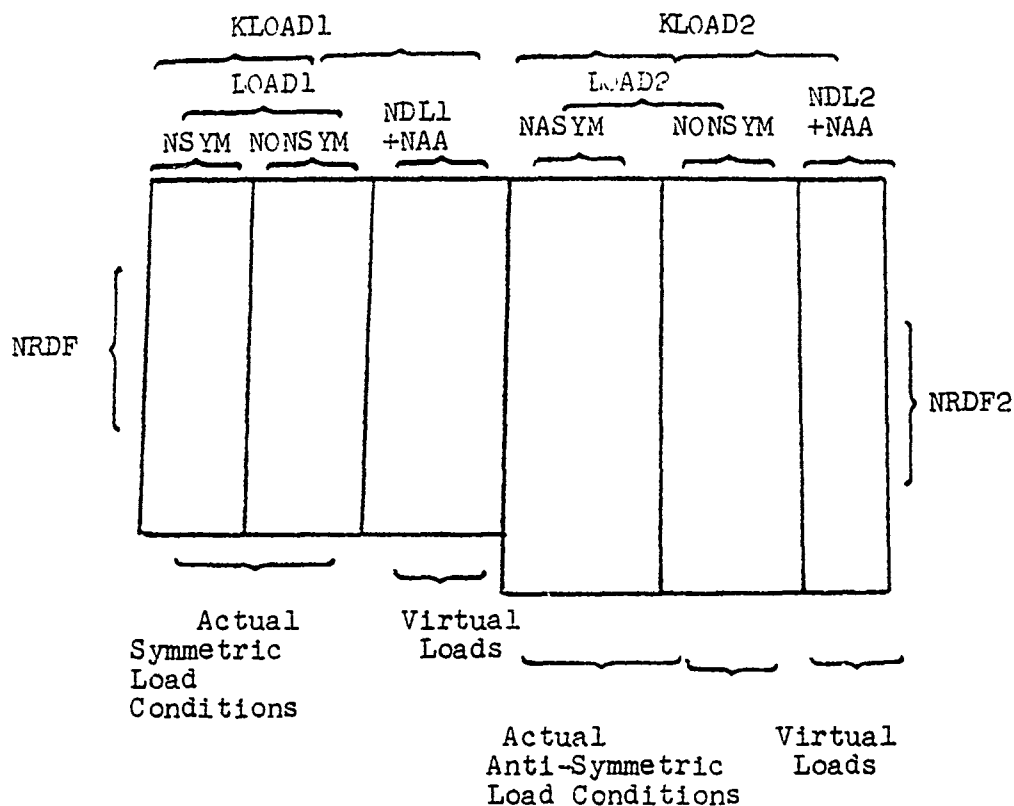
AFTER CALCULATION OF STRESSES



BEFORE ENTRY INTO SCALE ROUTINE

Figure 4: STRESS MATRIX STORAGE ALLOCATION

DISPLACEMENT MATRIX



Singly Subscripted

In-core for both in-core and out-of-core solutions.

FIGURE 5. DISPLACEMENT AND LOAD MATRIX STORAGE ALLOCATION